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ENVIRONMENTAL STATEMENT FOR THE SPACE SHUTTLE PROGRAM

FINAL STATEMENT

JULY 1972

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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<u>SUMMARY</u>

ENVIRONMENTAL STATEMENT

FOR THE

SPACE SHUTTLE PROGRAM

( ) Draft (X) Final

<u>Responsible Federal Agency</u>: National Aeronautics and Space Administration (NASA), Office of Manned Space Flight, Space Shuttle Program

1. (X) Administrative Action ( ) Legislative Action

2. The space shuttle is a piloted, recoverable, reusable space transportation system to provide rapid, easy, economical access to space. The shuttle can carry payloads of up to 29,500 kilograms (65,000 pounds) into orbit and return them to earth. The shuttle will replace most present launch vehicles and will greatly expand the Nation's flexibility in carrying out beneficial space activities. The space shuttle is expected to make its first orbital test flight in 1978, to be operational before 1980, and to operate for many years after that.

3. The potential for adverse program impact is small; such impacts as are foreseen will be local, short in duration, controllable, and environmentally acceptable.

4. Alternates to the space shuttle are more expensive and are not better environmentally than the proposed program.

5. a. Comments were requested from: CEQ, EPA, DOD, DOA, DOT, HEW, HUD, DOI, DOC, OMB, State, AEC, NSF, and FPC.

b. Comments were received from EPA on the February 1971 draft. Comments were received from DOA, DOT, DOD, DOC, DOI, HUD, HEW, AEC and EPA on the second draft statement (April 1972). All comments were given consideration in the preparation of this final statement.

6. The first draft statement, dated February 1971, was sent to CEQ in March 1971. A second draft was prepared because of modifications to the space shuttle configuration and was sent to CEQ in April 1972. This final environmental statement was made available to CEQ in July 1972.

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A. INTRODUCTION

1. Background

On January 5, 1972, the President announced that the United States should proceed at once with the development of a new type of space transportation system, a piloted reusable vehicle capable of carrying large payloads to and from orbit. This, the final environmental impact statement for the Space Shuttle Program, is submitted by the National Aeronautics and Space Administration (NASA) as required by the National Environmental Policy Act of 1969 and the April 23, 1971, guidelines of the Council on Environmental Quality (CEQ) on statements covering proposed Federal actions that might affect the environment.

A draft environmental impact statement, describing the concept then under consideration for the shuttle program, was issued over a year ago, on March 1, 1971. Comments were requested from the Council on Environmental Quality, the Office of Management and Budget, the Environmental Protection Agency (EPA), the Department of Transportation, the Department of Defense, and the Department of State. The availability of the draft statement was announced in the Federal Register on March 3, 1971.

Because of evolution of the shuttle concept since preparation of the March 1, 1971, draft environmental impact statement, and because of changes in the requirements for the preparation of impact statements, a second draft statement was made available for comments as prescribed by CEQ guidelines. It detailed the environmental implications of the development program now approved and reflected the results of environmental analyses and studies which have been undertaken during the past several years. This final environmental impact statement was prepared incorporating any additional data necessitated by the review of the draft. This final statement has been submitted to the CEQ and made available to the public.

This statement is limited to a treatment of the space shuttle as a transportation system for rapid, easy access to space for men and equipment, and covers the environmental effects associated with its development and eventual operations. When operational, the space shuttle will be able to carry many different payloads and to execute many different missions; if required, separate environmental statements will be prepared for those payloads which may have significant potential environmental implications.

2. Program Objectives and General Description

The space shuttle program objectives are:

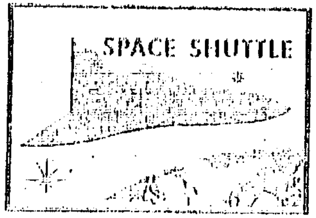
- To provide the means for routine, quick reaction, and economical access to and return from space needed for automated and manned civil and military uses of space in the 1980's and beyond.
- To reduce the cost of space operations substantially.
- To maintain an advanced U.S. space capability and to encourage greater international participation in space.

Development and operation of a space shuttle will assure that the United States will have a continuing, effective presence in space. The space shuttle will be a reusable space vehicle which will carry out various space missions in earth orbit. It will consist of two stages. The first stage, or booster, will be an unmanned solid fuel rocket. The second stage, or orbiter, will look like a delta-winged airplane and will be piloted to orbit and back to earth for an airplane-like landing.

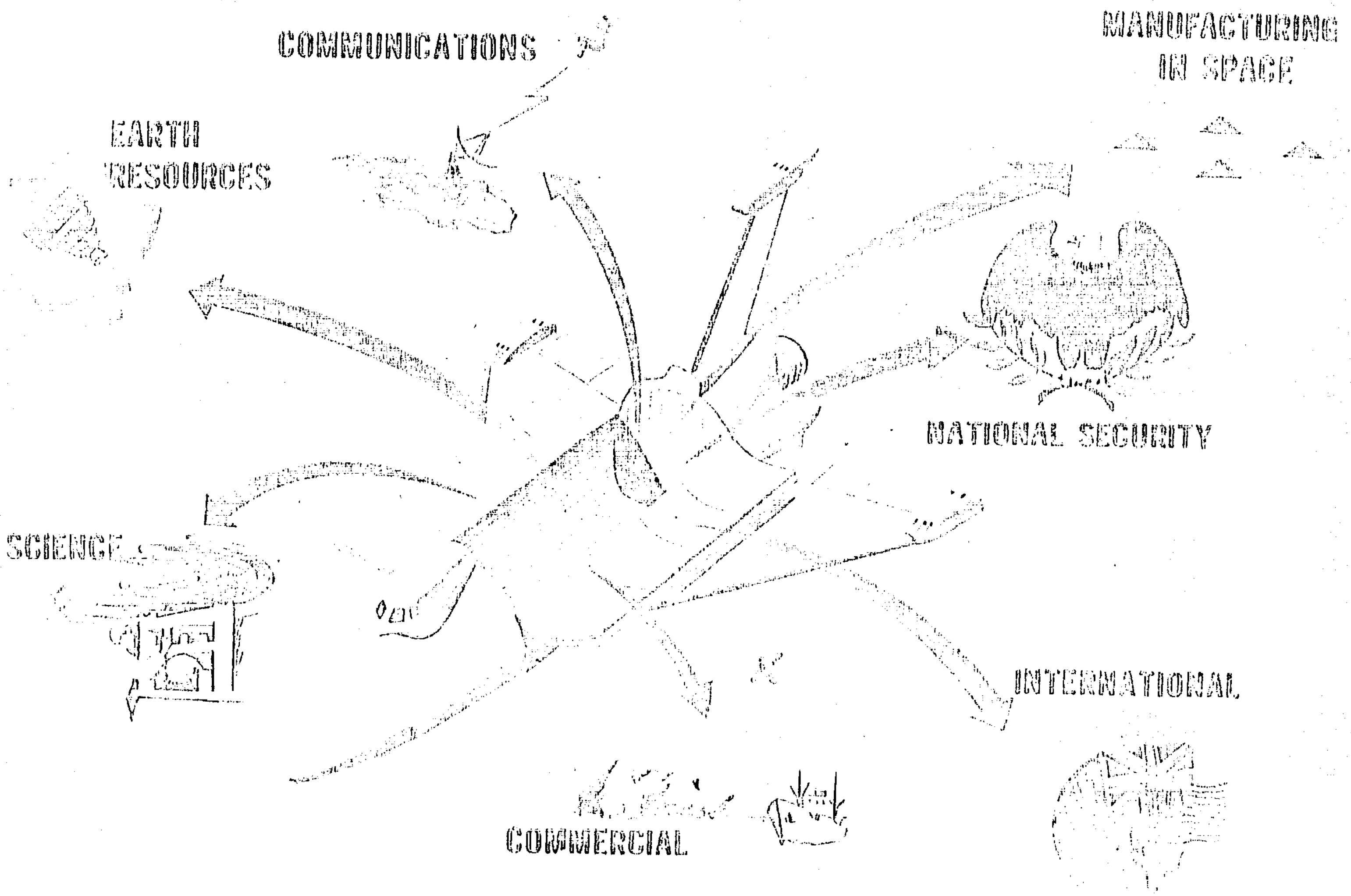
On the launch pad, the orbiter will be joined to the booster. Both the booster and orbiter engines will operate together until an altitude of about 55 to 65 kilometers (approximately 30 to 35 nautical miles) is reached.

The orbiter with its crew and payload then continues on to earth orbit for missions lasting up to 30 days, while the boosters return to earth to be recovered for reuse. When the orbiter mission is completed, the piloted vehicle will return to earth, landing like an airplane to be refurbished and reused.

Payload capability of the shuttle will be up to 29,500 kilograms (65,000 pounds). The shuttle will be used to carry into space virtually all of the Nation's civilian and military payloads: manned, man-tended, or automated (Figure 1A). These will include automated scientific space probes and earth orbiting solar and astronomical observatories. Applications payloads will include earth resources, environmental sensing, communications, meteorological, and geodetic satellites. The shuttle will provide transportation for operational and development payloads for the Department of Defense, NASA, the National Oceanic and Atmospheric Administration, and other users such as the Departments of



SHUTTLE WILL HAVE MANY USES



Interior and Agriculture. It will also be able to accommodate the future needs of commercial and international users.

It is estimated the shuttle will eventually carry out up to 50 space missions per year. Approximately 30 percent of the missions will be for the Department of Defense. About 80 percent of the missions will be to deploy, service, or recover automated satellite payloads. All the classes of missions currently being flown on existing launch vehicles ranging in capability from Thor-Delta up through Saturn IB will be carried out with the space shuttle which will therefore replace most of the single-use expendable launch vehicles now in use.

The National Aeronautics and Space Administration plans to develop the space shuttle over the next six years. Horizontal test flights are to begin in 1976, orbital test flights in 1978, and the complete space shuttle vehicle is expected to be operational before 1980.

3. Shuttle Benefits

Through its many earth applications and its effect on the economy, the space program has favorably benefited many segments of the Nation - science, commerce, industry, education, agriculture, aviation, communications, ecology, medicine, and national security. Advances in technical fields have been stimulated at an unprecedented pace and have been a significant factor in helping the United States to maintain a position of technological leadership.

Continued space activities can yield significant long-term improvements to life on earth. To achieve these improvements, it is first necessary to operate more economically in space so that its full utilization will be possible within the larger context of other national goals and programs. The shuttle will reduce the cost of space transportation by providing a reusable system with a flexible launch rate capability and a short turn-around time. In addition to the transportation savings, very significant economies will be realized in reduced payload costs due to relaxed weight and volume constraints, capability to revisit and return payloads for repair and reuse, and safe, intact abort of payloads.

Environmental quality stands high on the list of potential beneficiaries of the space shuttle program. Earth sensing and the corollary data analysis technologies are today largely still undergoing development but already show much promise in monitoring air and water pollution, land-use patterns, and other factors comprising environmental quality. Development and operation of the space shuttle, because of its capability of reducing costs and increasing flexibility, will foster the application of earth sensing technologies to the monitoring and control of environmental quality.

The same technologies can be applied to the improved management of the earth's resources, both renewable (e.g., food) and non-renewable (e.g., minerals), and extensive research and development in these applications is underway. Operation of the space shuttle will greatly contribute to conservation and wise utilization of these finite, and, in some cases, dwindling resources on a national and a global basis.

The shuttle will contribute to conservation of resources in yet another way. Reusability of nearly all the shuttle components and of the satellites and other payloads will reduce the consumption of structural metals, such as aluminum, steel, and titanium, and the valuable auxiliary materials, such as copper, silver, and gold, all used in current expendable launch vehicles and their satellite payloads.

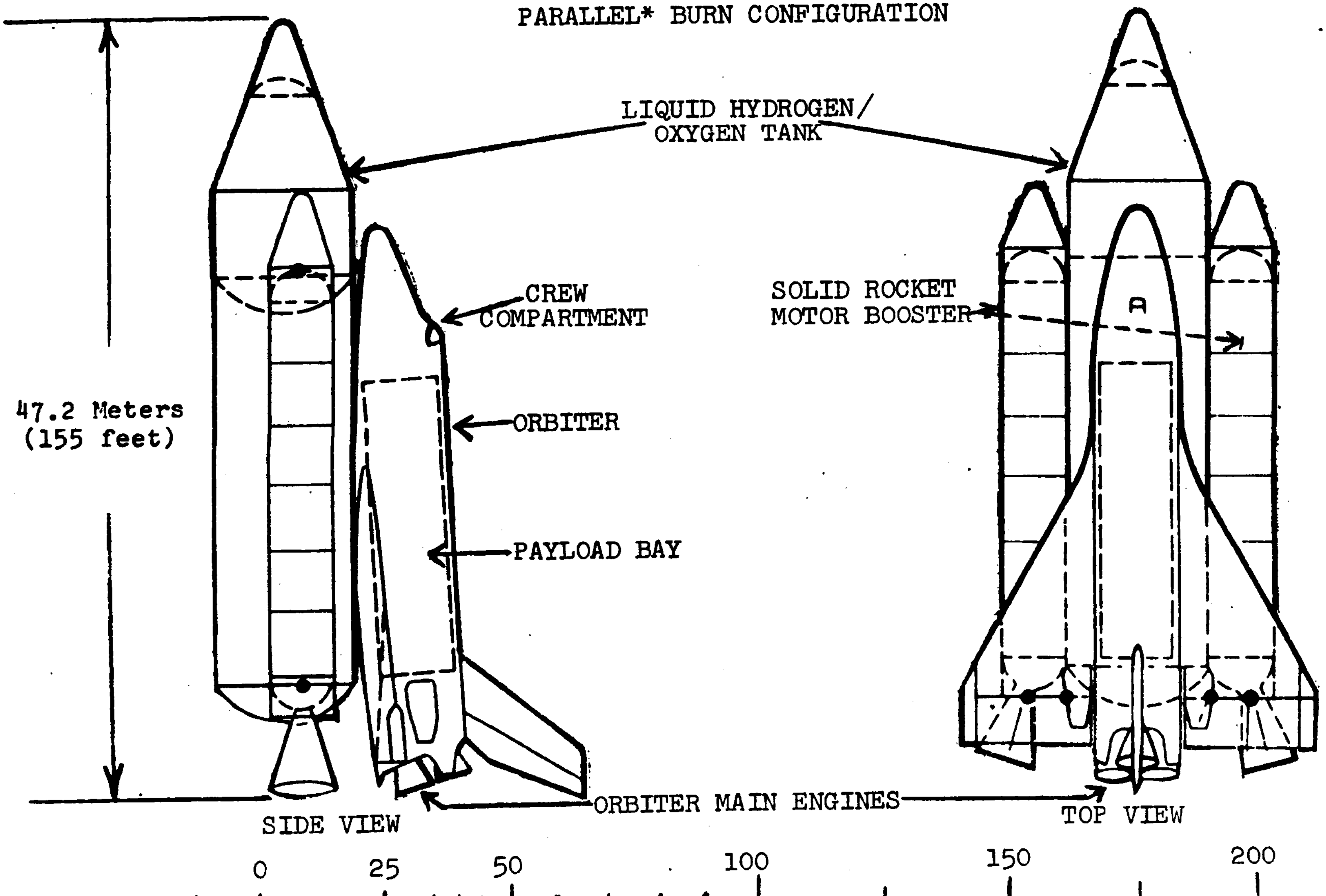
These benefits can be obtained at reasonable costs. Monetary costs are detailed in Appendix A, where it is shown that savings resulting from the reduction of operating costs of the shuttle below those of current methods will more than pay the costs of shuttle development.

Environmental effects are summarized in the following sections. They are shown to be highly localized, of short duration, and controllable. Where the possibility of some detrimental environmental impact exists, operational constraints will be imposed to preclude or minimize these impacts.

4. Space Shuttle Configuration (see Figure 1B)

Orbiter. The orbiter will be approximately 36 meters (120 feet) long and have a wing spread of 23 meters (75 feet). It will weigh about 91,000 kilograms (200,000 pounds) at launch. The manned orbiter will be propelled by three high pressure liquid hydrogen-liquid oxygen engines, each providing a thrust in space of 2,090,000 newtons (470,000 pounds). Fuels for these engines will be carried in an expendable external propellant tank attached to the orbiter and jettisoned when orbit has been achieved.

SPACE SHUTTLE
SOLID ROCKET MOTOR BOOSTER
PARALLEL* BURN CONFIGURATION



*Booster and orbiter engines are ignited and burn simultaneously from launch.

The crew of the orbiter will consist of a pilot, co-pilot, systems monitor, and payload specialist. The shuttle orbiter will experience a maximum load factor of 3 g's during launch and reentry and will have a cross-range maneuvering capability sufficient to permit return to the launch site after one orbital revolution.

Booster. The booster will consist of two solid-fueled rocket motors of approximately 13 million newtons (3 million pounds) thrust and weighing 635,000 kilograms (1.4 million pounds) each at launch. The solid rockets will burn out and be jettisoned at an altitude of about 55 kilometers (30 nautical miles) while the orbiter engines continue burning to carry the orbiter into space. The boosters will be decelerated in their descent by parachutes and/or rockets for landing in the water from which they will be recovered for refurbishment and reuse.

5. Mission Sequence and Environmental Effects

Normal space shuttle missions will commence with the launch, during which both booster and orbiter rocket motors are operating. Environmental factors in this phase are the possible short-duration effects on air quality and the rocket-generated noise. During the ascent, a sonic boom occurs some distance down range. After burnout of the two booster motors, they are jettisoned and they reenter the atmosphere for recovery about 185 to 370 kilometers (100 to 200 nautical miles) down range from the launch site. Sonic boom is a factor during booster reentry.

The orbiter continues on into orbit and its liquid hydrogen/liquid oxygen main propellant tank is jettisoned when empty. This tank is disposed of in a predetermined isolated ocean area.

No negative environmental factors have been identified with shuttle earth orbital operations.

Upon completion of the mission in orbit, orbiter retrorockets will be fired and the orbiter will then reenter the atmosphere, maneuver to the desired landing site, and land. Sonic boom is the chief environmental effect of the orbiter that must be considered during the return phase.

Abort situations conceivably could occur at launch, during ascent to orbit, in orbit, and during reentry, and their possible environmental effects are considered herein. However, aborts are deemed to be highly improbable; in any case, the environmental implications of such abort cases are of limited extent and duration.

6. Geographic Location of Program Activities

The initial launch and landing site will be at the Kennedy Space Center, Florida. This site will be used for research and development launches, expected to begin in 1978, and for all operational flights launched into easterly orbits. Facilities for all shuttle users at KSC will be provided by NASA, largely through modifications of existing facilities built for the Apollo and other programs.

Toward the end of the decade, it is planned that a second operational site will be phased in at Vandenberg Air Force Base, California, for shuttle flights requiring high inclination orbits. The basic shuttle facilities required at Vandenberg are planned to be provided by the Department of Defense.

Booster development responsibility rests with the Marshall Space Flight Center, Alabama, and that for the orbiter rests with the Manned Spacecraft Center, Houston, Texas. Development and testing activities will be carried out at these and other locations.

Rocket engine testing will be conducted in remote areas so that the noise and exhaust products can be adequately dispersed and controlled. For example, testing of the orbiter main engines will be carried out at the existing NASA Mississippi Test Facility, Bay St. Louis, Mississippi.

Environmental factors were carefully considered in the selection of these sites. The sites have sufficient control area surrounding them to eliminate any adverse effects on inhabited areas, persons, or property from noise or pollutants resulting from launch or testing activities. An important consideration in launch and landing site selection was the desire to minimize the effect of the sonic boom on populated areas.

Environmental impact statements for NASA activities at these installations are already in existence.*

*"Institutional Environmental Impact Statement," John F. Kennedy Space Center (including operations in Florida and at Vandenberg Air Force Base, California), dated August 11, 1971, submitted to the Council on Environmental Quality, September 29, 1971.
"Draft Environmental Impact Statement," Marshall Space Flight Center, dated February 1971, submitted to the Council on Environmental Quality, March 12, 1971.
"Environmental Impact Statement," Manned Spacecraft Center and White Sands Test Facility, dated July 1971, submitted to the CEQ, September 29, 1971.

Details of any significant environmental effects at these locations, including social, cultural, and demographic effects, will be provided, if necessary, in amendments to those statements.

B. POSSIBLE ADVERSE CONSEQUENCES

Of the environmental effects mentioned in the preceding section and further detailed in Section C, three may have some potential of adversely affecting the environment. These three are: (1) air pollution, (2) sonic boom, and (3) orbiter tank reentry. These and the measures to be taken to preclude or alleviate these effects are described below:

1. Air Pollution

Emissions of hydrogen chloride (HCl) from the solid boosters may create potentially hazardous conditions in the immediate vicinity of the launch site for a short period of time. Extensive theoretical calculations and some measurements made of solid rocket launches indicate that concentrations at ground level beneath the exhaust cloud are well below the maximum allowable 10-minute concentrations for man, and that the principal concern in the case of normal launches is the possibility of rain scrubbing out the HCl from the exhaust cloud in concentrations sufficient to have an adverse effect.

This same potential exists for the currently operational Titan III system. Standard operational procedures have been adopted that defer launches if weather conditions are such that the predictions of exhaust cloud concentrations, movements, and weather indicate unacceptable conditions. The success of these precautions is demonstrated by the launching of all twenty Titan III vehicles to date without incident. Similar operational constaints will be imposed on space shuttle launches to eliminate the possibility of unacceptable HCl concentrations in the air or on the surface. Furthermore, the launch site evaluation included full consideration of HCl emissions; the launch facilities will be laid out to ensure that any hazard potential is minimized.

In the event of on-pad fire or low-level abort of the booster with all the solid propellants consumed in the resulting fires, concentrations would be higher than for normal launches, but still within the allowable limits. Based on the demonstrated reliability of man-rated launch vehicles to date, and considering the space shuttle design, inspections, and quality control requirements, such an abnormal event is considered very unlikely.

2. Sonic Boom

As in other space launches, the shuttle launch imposes a focused sonic boom. It will be limited to a narrow area about 60 kilometers (33 nautical miles) down range from the launch site which may result in overpressures reaching as high as about 1,400 newtons per square meter (N/m^2)(30 pounds per square foot, or psf). As this gets into the range of overpressures that could possibly damage structures, the launch site and mission trajectories have been chosen so that the boom will occur over the ocean. There will be some constraints on the economic or recreational use of that limited ocean area during a launch period. As in the case of current launches, warning notices will be issued prior to shuttle operations.

Further down range over the open ocean, the reentering booster will cause a small sonic boom of about 144 N/m^2 (3 psf). This boom affords no hazard and further will occur over an ocean area already identified in advance of each shuttle operation as the booster recovery and return area.

Orbiter reentry sonic boom will not reach levels greater than about 48 N/m^2 (1 psf) except for a very small region where it will approach 96 N/m^2 (2 psf). Return trajectories will be controlled to avoid increases or focusing above this level over land. Based on the infrequent shuttle flight schedule and the low upper limit of this overpressure, the orbiter reentry sonic boom will not present a hazard.

3. Orbiter Tank Reentry

Both the spent booster and orbiter propellant tank will reenter the atmosphere during the course of each shuttle mission. The booster will be designed to be reused, and will thus be parachuted to a landing in the ocean at sufficiently low impact velocities to ensure survival and recovery.

The orbiter tank will be made to reenter and drop in a predetermined, remote ocean location away from commercial shipping lanes, fishing grounds, or recreational area. The orbiter tank will probably break up during atmospheric reentry. Appropriate warnings will be issued.

Orbiter abort situations introduce the possibility of orbiter tank explosion and fire should propellants still be present. During the early phase of launch, when large amounts of propellants remain, the affected area would be the normal down range area already treated as hazardous because of booster reentry. At later stages of the launch, much propellant would have been consumed and any abort-induced reentry would be like that of the normal mission. Should the tank retrorocket fail to fire in orbit, the tank would undergo uncontrolled reentry and disintegration much as does orbital debris which currently reenters periodically. The extent of this hazard has been considered and is small based on world-wide experience to date.

C. ENVIRONMENTAL EFFECTS

1. General

The relationship of the NASA space shuttle program to the environment is considered below covering the effects of exhaust emissions on air quality, the possible role of propellants on water quality, the question of engine noise, and the management of sonic boom. The questions of land use and cultural, social, and demographic effects are directly related to the sites of program activities and will be separately and fully treated as necessary in institutional environmental impact statements. Solid waste management is not considered to be a problem. No radioactive materials are planned to be used as part of the space shuttle transportation system.

2. Air Quality

Source and Nature of Emissions. The space shuttle flight system will be powered by chemical rocket engines. These engines operate by the combustion of a fuel and self-contained oxidizer. The types of propellants to be used by the shuttle are listed in Tables 1A and 1B. The products of combustion exhausted from the rocket nozzle may include compounds and molecular species which are not stable at ambient conditions, or which may react with

Table 1A
SUMMARY OF PROPELLANTS, LIQUIDS AND GASES

Booster Main Propulsion	Kilograms
Solid Propellant/Polymer Oxidizer Aluminum	1,090,000

Orbiter Main Propulsion System

Liquid Oxygen (LOX)	558,000
Liquid Hydrogen (LH_2)	95,300
LOX/LH_2 Tank Retro-rocket (Solid Propellant)	1,300

Orbit Maneuvering Propulsion System 1/ 2/

	ΔV=305 meters/sec	ΔV=763 meters/sec
Nitrogen Tetroxide (N_2O_4)(kg)	6,930	14,860
Aerozine-50 (A-50)(kg)	4,330	9,290
Helium (kg)	17	36

Orbiter RCS Fluids and Gases 2/

Biopropellant		or	Monopropellant	
Helium	14 kg		Helium	27 kg
Monomethyl Hydrazine (MMH)	1,060 kg		Hydrazine (N_2H_4)	3,450 kg
Nitrogen Tetroxide (N_2O_4)	1,700 kg			

Orbiter Hydraulic System: 215 kg Hydraulic Fluid (MIL-H-83282). Estimated loss of 5% per mission through external leakage.

Orbiter Auxiliary Power Unit (APU):
Lubricant - 27 kg
change out every mission
Helium - 9.1 kg
Hydrazine - 826 kg

Orbiter Fuel Cell Reactants: 2/
Oxygen - 658 kg
Hydrogen - 79.5 kg

Orbiter Air Breathing Engine System:

JP	
Space Mission	0 to 2,270 kg
Ferry (airport-to-airport)	Up to 22,700 kg at takeoff

1/These figures span the range of anticipated on-orbit change in velocity (ΔV) requirements.
2/Normally expended in space. Any residuals after landing will be contained for disposal.

Table 1B
SUMMARY OF PROPELLANTS, LIQUIDS AND GASES

Booster Main Propulsion	Lbs.
Solid Propellant/Polymer Oxidizer Aluminum	2,400,000

Orbiter Main Propulsion System

Liquid Oxygen (LOX)	1,230,000
Liquid Hydrogen (LH_2)	210,000
LOX/LH_2 Tank Retro-rocket (Solid Propellant)	2,900

Orbit Maneuvering Propulsion System 1/ 2/

	ΔV=1,000 fps	ΔV=2,500 fps
Nitrogen Tetroxide (N_2O_4)(lbs.)	15,282	32,721
Aerozine-50 (A-50)(lbs.)	9,552	20,451
Helium (lbs.)	37	79

Orbiter RCS Fluids and Gases 2/

Biopropellant		or	Monopropellant	
Helium	30 lbs.		Helium	60 lbs.
Monomethyl Hydrazine (MMH)	2,340 lbs.		Hydrazine (N_2H_4)	7,600 lbs.
Nitrogen Tetroxide (N_2O_4)	3,740 lbs.			

Orbiter Hydraulic System: 474 lbs. Hydraulic Fluid (MIL-H-83282). Estimated loss of 5% per mission through external leakage.

Orbiter Auxiliary Power Unit (APU): Lubricant - 60 lbs. change out every mission
Helium - 20 lbs.
Hydrazine - 1,820 lbs.

Orbiter Fuel Cell Reactants: 2/ Oxygen - 1,450 lbs.
Hydrogen - 175 lbs.

Orbiter Air Breathing Engine System:

JP	
Space Mission	0 to 5,000 lbs.
Ferry (airport-to-airport)	Up to 50,000 lbs. at takeoff

1/These figures span the range of anticipated on-orbit range in velocity (ΔV) requirements.
2/Normally expended in space. Any residuals after landing will be contained for disposal.

the ambient atmosphere. Knowledge of the detailed composition of rocket exhaust gases is based on thermochemical calculations and confirmed by thrust measurements and rocket plume studies. Major chemical species emitted by the space shuttle rocket engines are listed in Table 2.

Of the major exhaust constituents, carbon monoxide (CO), hydrogen chloride (HCl), and alumimum oxide (Al_2O_3) could be classified as air pollutants. Though the carbon monoxide will generally completely oxidize to carbon dioxide in the plume at low altitudes[(1)*], it is retained in the following discussion for conservatism. The molecular weights and maximum allowable concentrations for a 10-minute, emergency exposure of industrial workers (MAC_{10}) for CO and HCl as recommended to military and space agencies by the Committee on Toxicology, National Research Council[(2)] and for Al_2O_3[(3)], are listed in Table 3.

In the upper atmosphere, water and carbon dioxide may be considered as potential pollutants due to their low natural concentration, and their possible influence on the earth's heat balance and on the ozone and electron

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*Numbers in the superscript parentheses are references, see Appendix B.

Table 2
Exhaust Products
Percent by Weight

Product Solid Rocket Motor	Weight %
HCl	20.90
Cl_2	0.06
CO^2	24.37
N_2	8.50
H_2O	10.39
H_2	2.11
CO_2	4.32
OH & H	0.02
Solid Particulates	
Aluminum Oxide	28.34
Aluminum Chloride	0.02
Iron Chloride	0.97
	100.00
Orbiter Main Propulsion	
H_2O	100.00
H_2	Trace
Auxiliary Power Unit	
NH_3	28.0
N_2	28.0
H_2	44.0
	100.0

Table 3
SELECTED ROCKET ENGINE COMBUSTION PRODUCTS
MOLECULAR WEIGHTS AND 10-MINUTE MAXIMUM ALLOWABLE
CONCENTRATIONS (MAC_{10}) FOR MAN[2][3]

Fuel Component	Molecular Weight	MAC_{10}
CO	28.01	1,500 ppm
HCl	36.47	30 ppm
Al_2O_3	101.94	50 mg m^{-3}

concentration. The dispersion characteristics within selected layers of the atmosphere are shown in Table 4.[4][5]

The distribution of combustion products into these layers for the space shuttle is shown in Tables 5A and 5B.

<u>Environmental Effects - Flight Operations</u>. In a normal launch, the exhaust products are distributed along the vehicle trajectory (for about 135 seconds for the booster and about 8 minutes for the orbiter). Due to the acceleration of the vehicle, the quantities emitted per unit length of trajectory are greatest at ground level and decrease continuously along the flight path.

To permit assessment of potential air pollution from a normal launch, the amounts of CO, HCl, and Al_2O_3 resulting from the normal launch of a space shuttle have been calculated. The motion and diffusion of the exhaust cloud rising from the launch pad after launch is calculated for the appropriate exhaust products and atmospheric conditions.[6][7] The result of most importance is the history of the concentration of the pollutant at ground level downwind of the launch point should wind currents move a portion of the cloud to the ground. Results for

Table 4
DISPERSION CHARACTERISTICS WITHIN SELECTED ATMOSPHERIC LAYERS(4)(5)

Atmospheric Layers; Altitude Range	Temperature Structure	Wind Structure	Characteristic Mixing Rate
Below noctural inversion 0-500 m	Increase with height	Very light or calm	Very poor
Below subsidence inversion 0-1500 m	Decrease with height to inversion base	Variable	Generally fair to inversion base
Troposphere (above boundary layer) 0.5-10 km	Decrease with height	Variable; increase with height	Generally very good
Stratosphere 10-50 km	Isothermal or increase with height	Tends to vary seasonally	Poor to fair
Mesosphere/Thermosphere Above 50 km	Decrease with height	Varies seasonally	Good

Table 5A
COMBUSTION PRODUCTS OF CONCERN EMITTED BY THE
SPACE SHUTTLE VEHICLE - PARALLEL SRM BOOSTERS AND ORBITER LOX/LH_2 ENGINES -
INTO SELECTED ATMOSPHERIC LAYERS

Atmospheric Layer	Altitude Range	Combustion Product	Single Mission Quantity Emitted (Kilograms) SRM	Orbiter
Surface Boundary Layer	0-500 m	CO	37,200	
		CO_2	6,600	
		HCl	31,900	
		Cl_2	91.6	
		Al_2O_3	43,300	
		H_2O	15,870	19,520
Troposphere	0.5-10 km	CO	113,100	
		CO_2	20,100	
		HCl	96,900	
		Cl_2	278	
		Al_2O_3	131,600	
		H_2O	48,100	62,200
Stratosphere	10-50 km	CO	115,100	
		CO_2	20,440	
		HCl	98,800	
		Cl_2	284	
		Al_2O_3	134,100	
		H_2O	49,900	118,000
Lower Mesosphere	50-67 km	CO	-0-	
		CO_2	-0-	
		HCl	-0-	
		Cl_2	-0-	
		Al_2O_3	-0-	
		H_2O	-0-	49,000
Mesosphere/ Thermosphere above	67 km	H_2O		402,50(

COMBUSTION PRODUCTS OF CONCERN EMITTED BY THE SPACE SHUTTLE VEHICLE - PARALLEL SRM BOOSTERS AND ORBITER LOX/LH_2 ENGINES - INTO SELECTED ATMOSPHERIC LAYERS

Atmospheric Layer	Altitude Range	Combustion Product	Single Mission Quantity Emitted (lbs.) SRM	Orbiter
Surface Boundary Layer	0-1,600 ft	CO	81,883	
		CO_2	14,515	
		HCl	70,224	
		Cl_2	202	
		Al_2O_3	95,222	
		H_2O	34,900	43,000
Troposphere	0.27-5.5 n.mi.	CO	249,159	
		CO_2	44,168	
		HCl	213,682	
		Cl_2	613	
		Al_2O_3	289,748	
		H_2O	106,000	137,000
Stratosphere	5.5-27 n.mi.	CO	253,838	
		CO_2	44,997	
		HCl	217,694	
		Cl_2	625	
		Al_2O_3	295,189	
		H_2O	108,000	255,000
Lower Mesosphere	27-36 n.mi.	CO	-0-	
		CO_2	-0-	
		HCl	-0-	
		Cl_2	-0-	
		Al_2O_3	-0-	
		H_2O	-0-	106,000
Mesosphere/ Thermosphere above	36 n.mi.	H_2O		870,000

the three pollutants are shown in Figures 2, 3, and 4, respectively. In each case, three alternative meteorological conditions characteristic of the Kennedy Space Center are used to show the dependence upon wind and temperature appropriate to different seasons. Similar effects are expected at Vandenberg Air Force Base. These conditions are those which generally produce the largest predicted concentrations of pollutants at ground level. In all normal launch cases, the peak concentrations are well below the applicable maximum allowable 10-minute concentration levels shown in Table 3.

From the point of view of potential air pollution, the worst case accident would be a pad abort with complete burning of all solid rocket propellants on the pad. Exhaust cloud concentrations of CO, HCl, and Al_2O_3 have been calculated as a function of distance downwind of the launch pad for this abort case by the method described previously, and the results are shown in Figures 5, 6, and 7[6][7], respectively. The figures show that peak concentrations are about 5 to 10 times larger for this case than for the normal launch, but would still be below the 10-minute maximum allowable

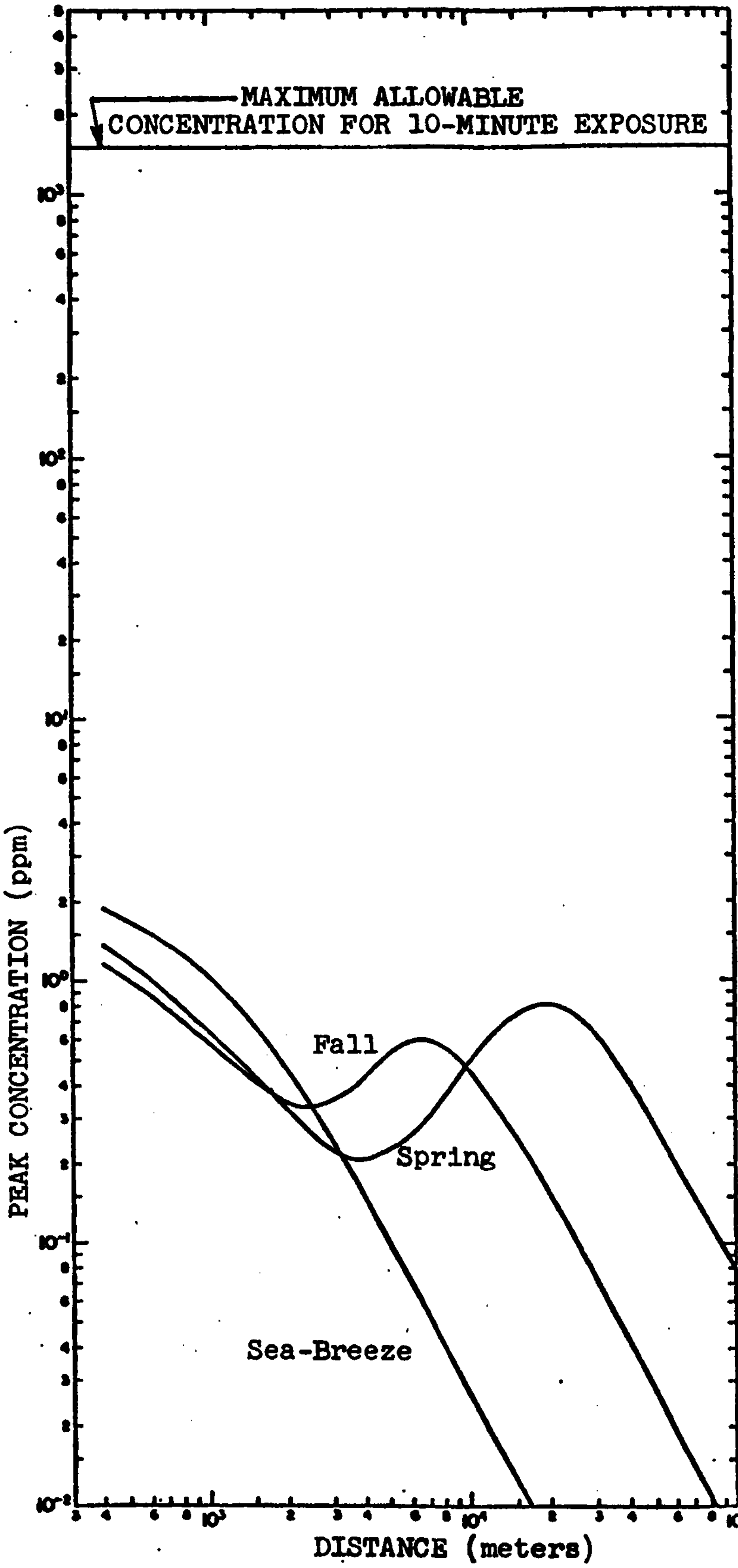


Figure 2. Peak centerline concentration of CO at the surface downwind from a normal launch.

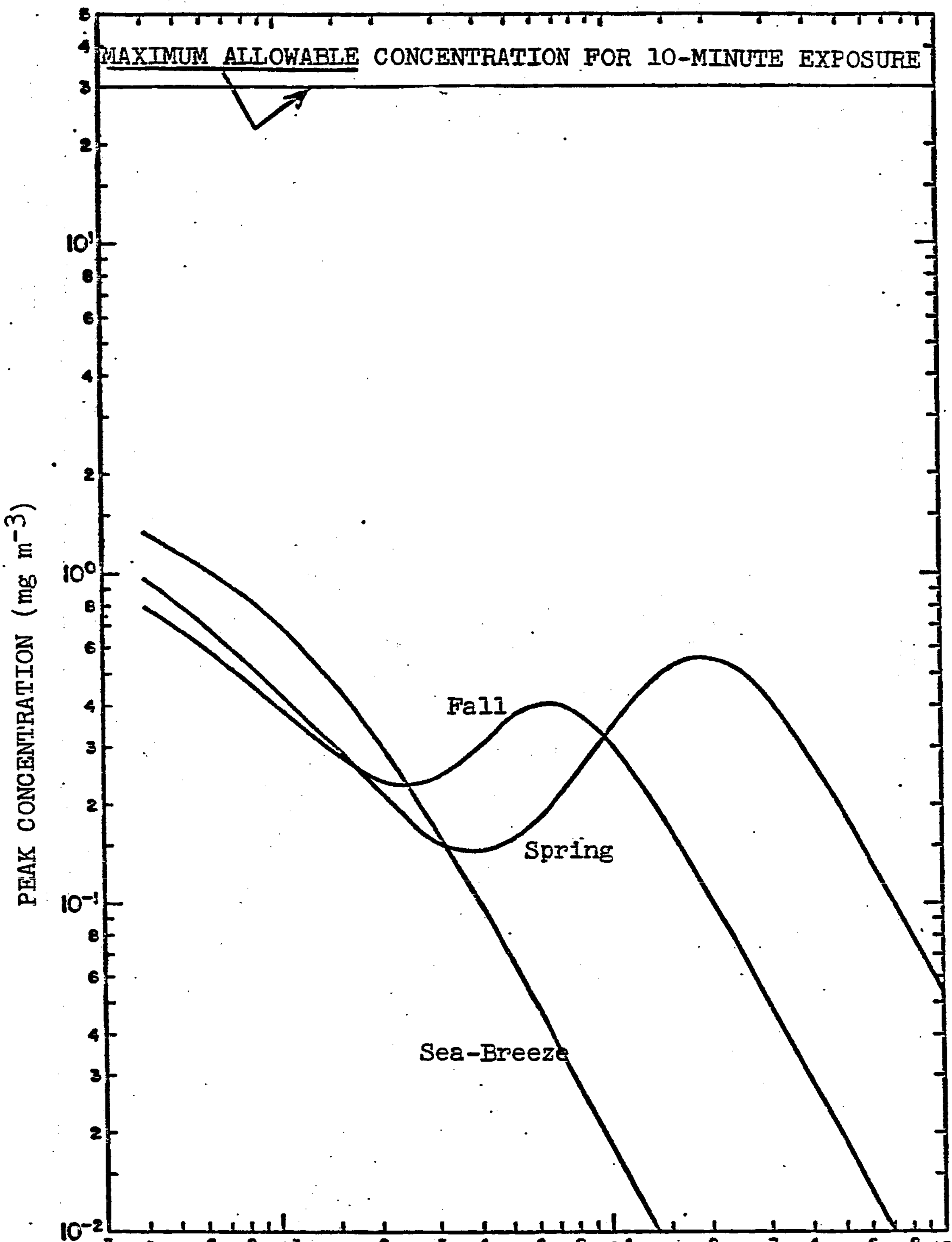


Figure 3. Peak centerline concentration of Al_2O_3 at the surface downwind from a normal launch

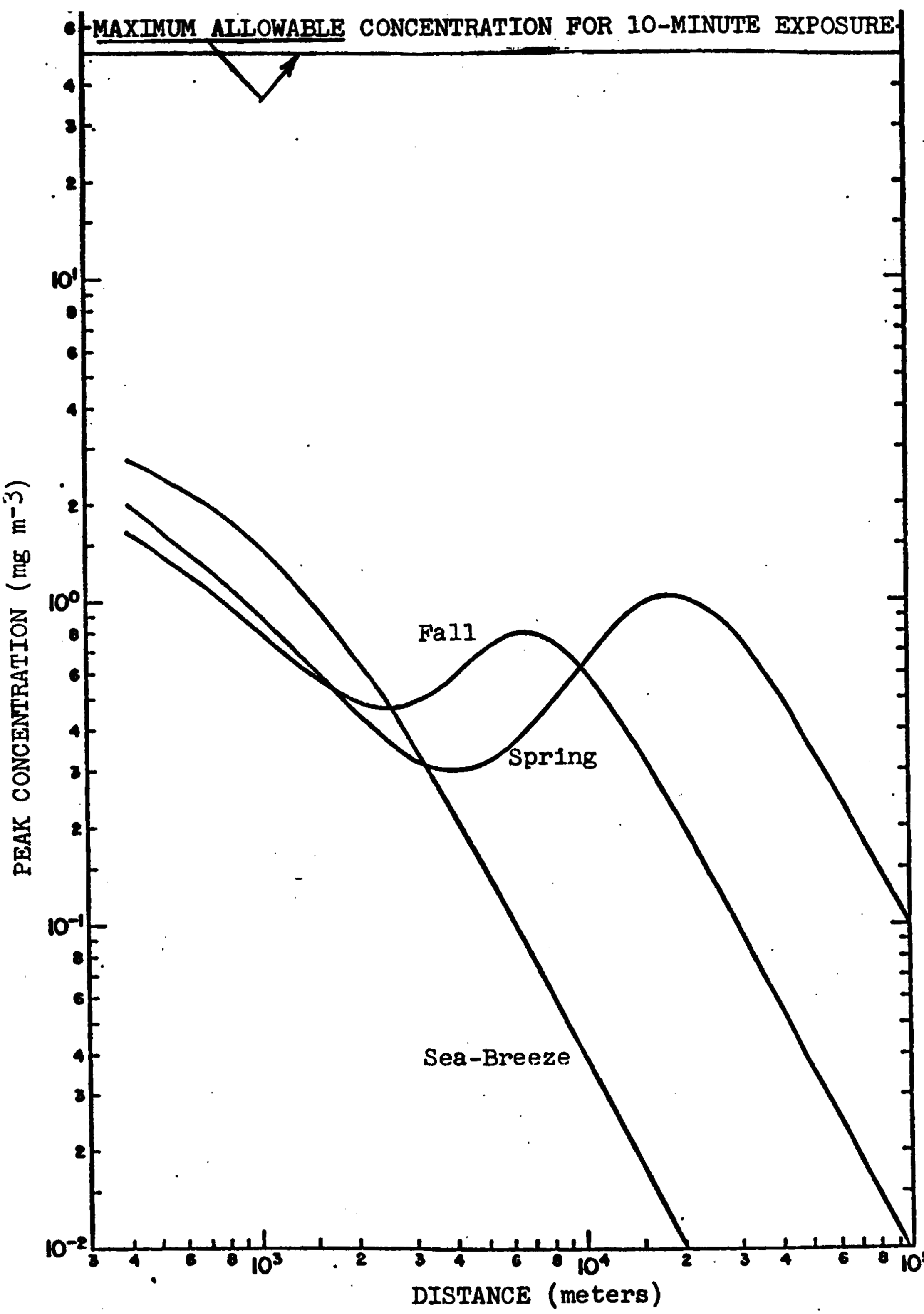


Figure 4. Peak centerline concentration of Al_2O_3 at the surface downwind from a normal launch

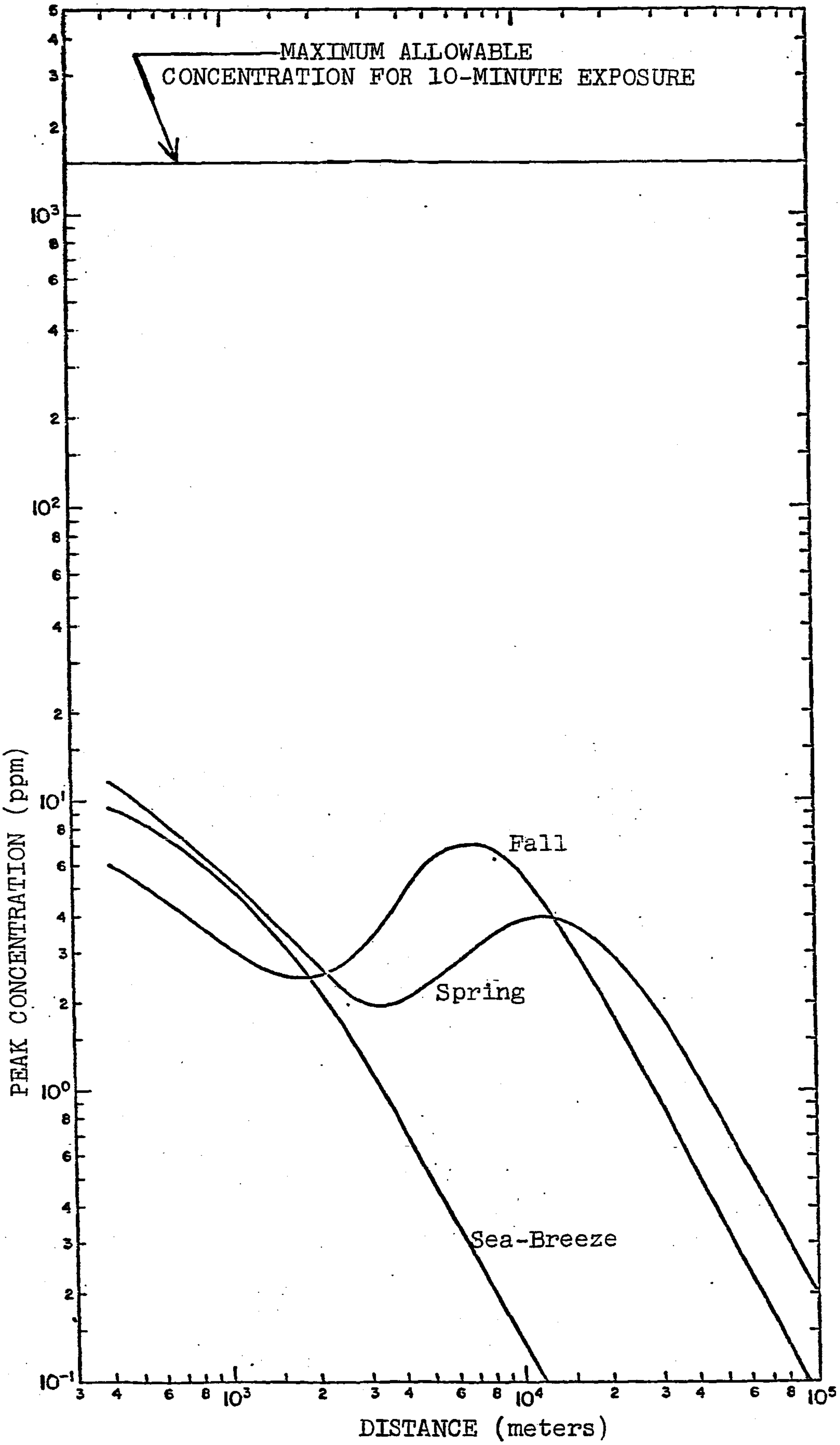


Figure 5. Peak centerline concentration of CO at the surface downwind from a pad abort.

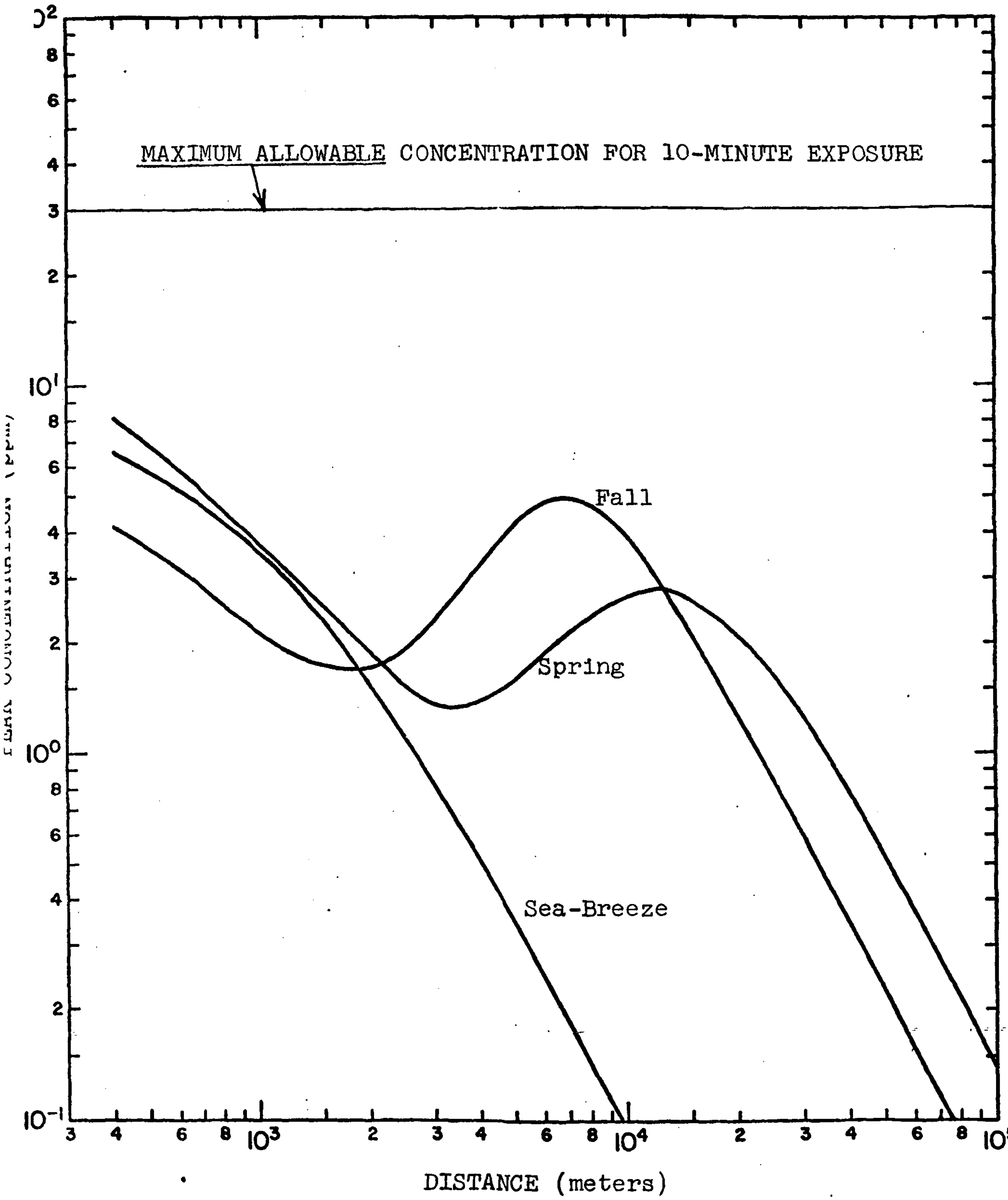


Figure 6. Peak centerline concentration of HCl at the surface downwind from a pad abort.

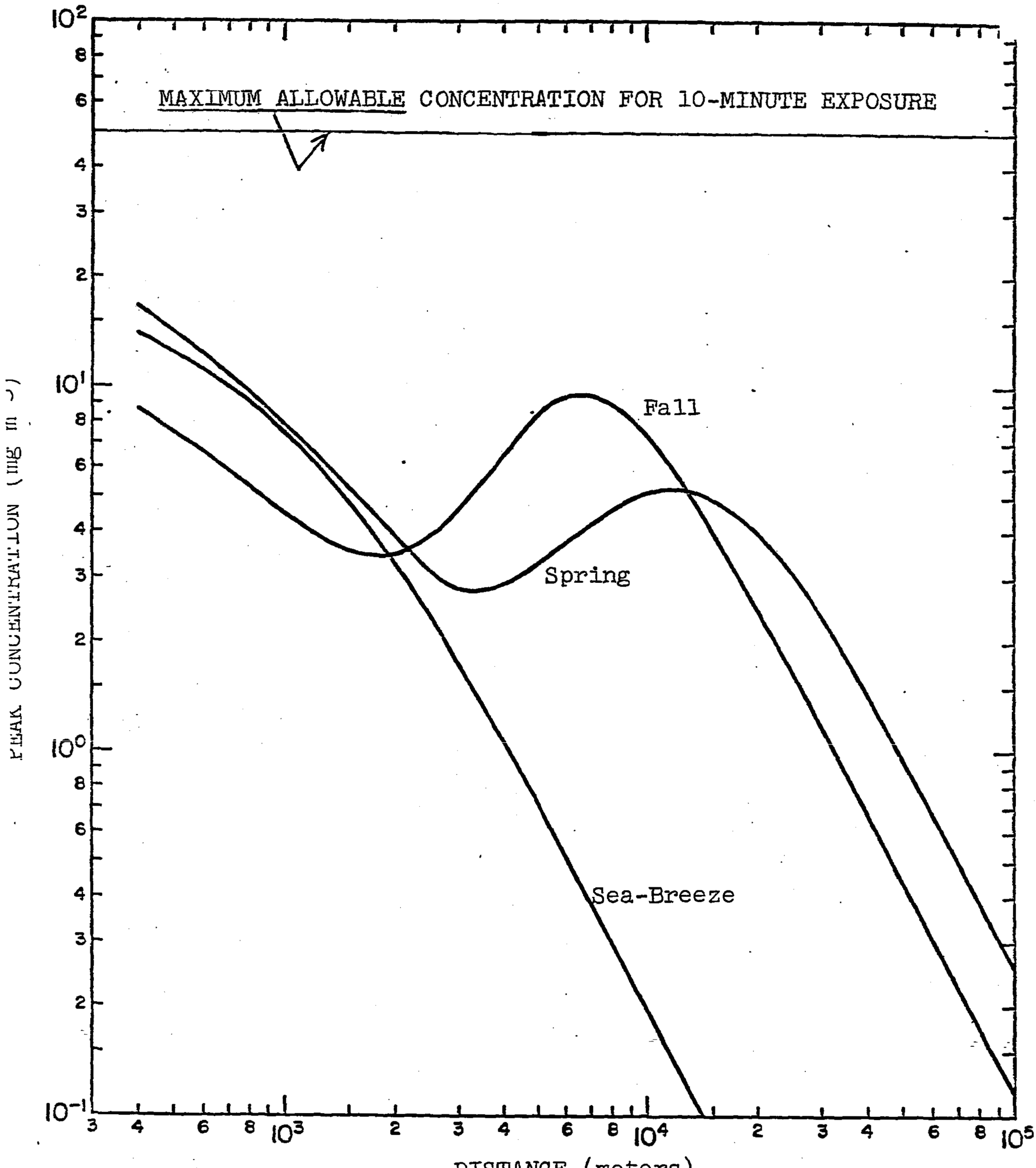


Figure 7. Peak centerline concentration of Al_2O_3 at the surface downwind from a pad abort.

concentration levels of Table 3 for distances beyond 300 to 400 meters (1,000 to 1,300 feet), well within the controlled area.

Additional criteria have been developed for the general public for exposure to hydrogen chloride.[8] Guides for hydrogen chloride are:

Concentration	Effect
1 - 10 ppm	Odor threshold
5 - 10 ppm	Disagreeable or irritating

Concentration	Recommended Limit
4 ppm	10-minute public limit
2 ppm	60-minute public limit

These concentration levels are time-weighted averages considered to present no health hazards. Excursions above these levels are likely to produce objectionable odors and/or irritation. Although at some locations downwind the recommended limits for 10- and 60-minute exposures may be exceeded briefly for a pad abort (see Figure 6), the time dependence of the concentration at these locations is such that the time-averaged concentration is less than the recommended limits for the specified periods of time.

The ability of space shuttle operations to meet the

National Primary and Secondary Ambient Air Quality Standards has been evaluated. For CO, the peak concentration of approximately 8 parts per million which would be reached for the order of a few minutes in the case of a pad abort (Figure 5) is well below the 35 parts per million maximum one-hour concentration allowed.(9) For Al_2O_3 which is regarded as an inert particulate only(10), the peak concentration of approximately 9 milligrams per cubic meter downwind at the surface (Figure 7) appears greater than the National Secondary Ambient Air Quality Standard for particulates of 0.15 milligrams per cubic meter - maximum 24-hour concentration.(9) However, the peak concentration would persist for the order of a few minutes only. When averaged over a 24-hour period, the ambient air concentration for the pad-abort situation depicted would fall below the standard. There is presently no National Primary and Secondary Ambient Air Quality Standard for HCl. As described in the paragraph above, the time-averaged concentration is less than the public limits recommended by the National Academy of Sciences/National Research Council.(8)

The particulate deposition of Al_2O_3 has also been considered. While a large fraction of the Al_2O_3 is generated at altitude, eventual settling of all of the Al_2O_3 to the ground was presumed. The areas immediately surrounding the solid rocket motor test sites, the launch pads and that overflown by the shuttle during ascent are the only areas repeatedly affected. The test sites and launch pads are controlled areas; the deposition of the inert Al_2O_3 is a nuisance only which will be accommodated through proper design. The average value of Al_2O_3 deposition in a typical launch corridor was calculated. At a flight rate of 50 per year, the fall out would be approximately 0.0058 kilograms per square meter (0.0012 pounds per square foot) per month. Since the trajectories of all space shuttle launches will largely be over the ocean, no significant fall out on land is envisioned and the fall out levels are too small to be of significance for the ocean.

The National Academy of Sciences/National Research Council Report(8) summarizes the known effects of HCl on wildlife. The effects of even the predicted peak ground level concentrations of 9 ppm for a pad abort (indicated in Figure 6) are nil.

HCl is reported[8] to be of only minor concern as to its effects on vegetation in comparison to other phytotoxic air pollutants such as ozone, hydrogen fluoride and ethylene. The threshold of injury is apparently 5 to 10 ppm if continued for a few hours. In the space shuttle worst case situation (a pad abort), this threshold limit would be reached (Figure 6) for the order of a few minutes and only in the immediate environs of the pad itself.

It should be noted that, since the outset of the manned space program through April 1972, 100 per cent of the NASA manned-rated launch vehicles have been successful through first staging. It is expected that the reliability of the booster and orbiter will be as good as that demonstrated to date by manned launch vehicles.

Upper Atmosphere Effects. No adverse atmospheric pollution effects of shuttle operations are foreseen in the troposphere (the region of the atmosphere up to about 10 km) because of the short residence time of particulates and the rapid mixing with the ambient atmosphere of shuttle-produced water vapor and gases, except for HCl scavenging by rain in the atmospheric boundary layer (i.e., from the surface of the earth up to approximately 1,000 meters).

The stratosphere (the region of the atmosphere between about 10 km and 50 km), because of its temperature increase with altitude, is relatively stable compared with the unstable troposphere. Consequently, the dispersion time of gases deposited in the stratosphere may be up to two years or more as compared to a dispersion time of days in the troposphere. The stratosphere contains the major atmospheric gases, oxygen and nitrogen, plus natural quantities of the minor constituents - carbon dioxide, water vapor, ozone, aerosols, sulphates, nitrates, and other trace gases and elements.

The possible short- and long-term effects upon the radiation balance of the earth because of increased absorption and scattering of radiation that might result from large increases in carbon dioxide and water vapor in the stratosphere were the subject of a recent special study[11] of critical environmental problems. The study examined very high levels of carbon dioxide and water vapor in the stratosphere and concluded there was no evidence of damaging environmental effects. At a flight rate of 50 missions per year, the shuttle would emit less than one ten-thousandth of the annual amount of CO_2 and water vapor that the study had found to be acceptable; no negative environmental effects in the stratosphere are expected as a result of shuttle operations.

The cited study also considered the effect of stratospheric particulates. If particulates that have residence times on the order of years were constantly added to the stratosphere, there would be an increase in stratospheric temperature. The shuttle particulates (Al_2O_3) are expected to range from about 1 micron up to 40 microns in diameter with an average diameter of approximately 10 microns[12], for which the residence time will only be on the order of a few days. Thus, the shuttle particulates are not expected to influence stratospheric temperature.

The mesosphere (the region of the atmosphere between about 50 and 80 km) has a good characteristic mixing rate and therefore the small amount of shuttle engine exhaust by-products (Table 5) deposited in this region will have an insignificant environmental effect. Only water vapor is emitted to the thermosphere (above 105 km), and the total amount which would be introduced assuming

50 missions each year is about one ten-thousandth of the amount present naturally at these altitudes.[13]

Hydrogen chloride emissions have a potential of producing a change in the ionization of the D and E regions of the ionosphere. Only the orbiter hydrogen/oxygen (HO) tank retrorocket will produce HCl emissions in this region, and only 274 kilograms (600 pounds) of HCl per flight will be emitted above an altitude of 67 km. The effects of emissions of this quantity on the ionization level are insignificant.

There are two emissions to consider during the space shuttle orbiter reentry. One is due to the effect of the orbiter shock wave on the air that produces nitric oxide. The other is the ablation of the thermal protection materials that produces carbon and silicon. These will be produce in the upper mesosphere at altitudes of 65 to 85 km (approximately 35 to 46 nautical miles). The vehicle is expected to produce less than 6,000 kilograms (approximately 13,000 pounds) of nitric oxide and less than 4,000 kilograms (approximately 9,000 pounds) of carbon and silicon per flight.

Current models of the atmosphere in this region indicate that this nitric oxide would be dispersed and destroyed within ten days. The carbon and silicon diffuse downward to the earth.

The possibility that ionization, induced in the shock layer during orbiter reentry and remaining in the wake, may be sufficient to create a significant effect on telecommunications or in solar-terrestrial relationships is under study. Estimates indicate that ion recombination to background levels will occur within one day.

Environmental Effects - Engine Tests. Engine tests differ from normal launches in that all of the propellants used are consumed at ground level. For the solid rocket motors, this case can be no worse than the worst case abort treated in the previous section, and the pollutant concentrations would be at worst equal to those of Figures 5 through 7.

All liquid propellant rocket engines used in the space shuttle are subjected to acceptance firing tests. The quantity of propellant consumed in these tests is in the range of one-quarter to twice the propellant consumed in flight, typically about one-third. Also, research and developmental activities result in the consumption of propellants at a similar level. For the orbiter main propulsion system, the product of combustion is water vapor. Tests of the other smaller engines used by the space shuttle would have no significant effects due to the small amount of emittants produced (Table 1).

Engine acceptance tests are performed at relatively remote sites, and access to the sites is controlled. Suitable precautions are taken to ensure the safety of the test crew, including remote operation and protective equipment.

Environmental Effects - Effects of Rain. In addition to dispersal by air currents, possible precipitation (rain) scavenging of HCl from the solid rocket exhaust cloud has been analyzed.(7) This phenomenon may occur only if the space shuttle is launched during rain showers or if such showers occur along the first 100 kilometers (54 nautical miles) of the downwind trajectory of the elevated ground cloud of the exhaust products. If this trajectory is over water rather than land, there are no potential harmful effects because of immediate dilution. For the over-land trajectories of the exhaust cloud, the possible harmful effects of rain containing HCl will be analyzed prior to each firing. If the calculations predict unfavorable conditions, the launch will be postponed.

3. Water Quality

Source and Nature. With planned recovery of all elements of the space shuttle except the orbiter tank, the potential impact of the program on water quality is limited to:

- On-pad accidents and propellant spills which may result in run-off of propellants to local drainage systems
- In-flight failures which may result in vehicle hardware and propellant landing in the ocean
- Controlled reentry of spent booster and orbiter hydrogen/oxygen tanks (treated separately in this statement)

Provisions such as dikes, catch basins, etc., are made for containing on-pad spills and disposing of the spilled propellant without contaminating the water (or air) environment. On-pad vehicle failures would normally be expected to result in a fire that consumed most or all of the propellants, and, thus, have been handled in the section on air quality. Any unconsumed propellant would be treated in the same way as a spill.

Impact on the Environment. Potential sources of pollutants to the marine environment and the major pollutants are:

Hardware	-	Heavy metal ions and miscellaneous compounds
Solid propellants	-	Ammonium perchlorate
Liquid propellants	-	Monomethyl Hydrazine, N_2H_4, Aerozine-50, N_2O_4
Lubricants, hydraulic-fluid		Hydrocarbons

Possibilities of water pollution are primarily associated with toxic materials which may be released to and are soluble in the water environment. Rocket propellants are the dominant source of such materials. A secondary consideration relates to oils and other hydrocarbon materials which may be essentially immiscible with water but, if released, may float on the surface of the water. Quantities of hydrocarbons used are small (Table 2).

Jettisoned or reentered hardware will corrode and thus contribute various metal ions to the environment.

The rate of corrosion is slow in comparison with the mixing and dilution rate expected in a marine environment, and, hence, toxic concentrations of metal ions are not expected to be produced. The miscellaneous materials (e.g., battery electrolyte, hydraulic fluid) are present in such small quantities that, at worst, only extremely localized and temporary effects would be expected.

The chief potential for water pollution is the propellants, and since in a normal launch essentially all propellants or propellant products are injected into the atmosphere and the hardware is recovered (except for the orbiter tank), the case of abnormal launch is considered. In the event of an in-flight failure in the early stages of flight, the booster and orbiter tank would probably impact intact. The orbiter would be expected to separate intact and return to the launch site.

Tables 6A and 6B show the amounts of propellant remaining in the booster and orbiter at various times during the ascent phase, and thus potentially available for release to the environment at that point in normal flight or following an abort. Shown also are the downrange location of the corresponding impact points.

Table 6A
SPACE SHUTTLE PROPELLANT QUANTITIES REMAINING

Time from Launch (Sec.)	Booster		Orbiter	
	PR 1/	IP 2/	PR 1/	IP 2/
0	1,090,000	0	653,000	0
50	653,000	46.3	590,000	46.3
100	218,000	116.7	524,000	116.7
125 3/	-0-	257	485,000	257
150			458,000	318
330			211,000	1,090
490			13,600	5,000
500 4/			-0-	-0-

1/PR = Propellant Remaining (kg)
2/IP = Downrange Impact Point Location from Launch Site (km)
3/Staging
4/Orbit Insertion

Table 6B
SPACE SHUTTLE PROPELLANT QUANTITIES REMAINING

Time from Launch (Sec.)	Booster		Orbiter	
	PR 1/	IP 2/	PR 1/	IP 2/
0	2,400,000	0	1,440,000	0
50	1,440,000	25	1,300,000	25
100	480,000	63	1,155,000	63
125 3/	-0-	139	1,070,000	139
150			1,010,000	172
330			465,000	590
490			30,000	2,700
500 4/			-0-	-0-

1/PR = Propellant Remaining (lbs.)
2/IP = Downrange Impact Point Location from Launch Site (n. mi.)
3/Staging
4/Orbit Insertion

The solid rocket booster propellant would continue to burn with the products of combustion as listed in Table 2 being dispersed into the air or absorbed into the ocean water. Any unburned solid propellant would slowly disperse.

Table 7 shows the estimated maximum allowable concentrations (MAC) for the chemical species of concern.(10)(14) The values in Table 7 are estimates for trout and are not expected to differ significantly for many fish species. Threshold Limit Values in air for man are shown for comparison. Critical materials are hydrazine and Aerozine 50.

Impact of the orbiter tank would release liquid hydrogen and liquid oxygen which would burn or evaporate rapidly into the atmosphere. The two toxic materials (low maximum allowable concentration), hydrazine and Aerozine 50, are contained in the orbiter only, and would be returned to the launch site. However, if the orbiter were forced to abort to a water landing, these materials would enter into the water. The quantities listed in Table 1 would be the maximum quantity involved and would dilute to non-toxic levels of concentration within the area affected by the emergency landing.

Table 7
MAXIMUM ALLOWABLE CONCENTRATIONS (MAC)
IN WATER FOR FISH AND IN AIR FOR MAN

Chemical Species	TLV* for Man, ppm (air)	MAC for Fish, mg/l (water)	Comments
Hydrazine (N_2H_4)	1.0[10]	0.7[14]	MAC for fish is the experimental value for trout which lost equilibrium after a 24-hour exposure.
Aerozine 50 (A-50)	---	0.53	Based on the sum of the toxic effects of hydrazine and UDMH.
Nitrogen Tetroxide	5[10]	95	MAC for fish estimated from the value for nitric acid. Nitric acid is a weaker oxidant and has a MAC value for fish of 100 mg/l.
Ammonium Perchlorate (NH_4ClO_4)	---	136[14]	MAC for fish computed from the 96-hour median TLV for ammonium dichromate (considering oxidizing properties only).

*Threshold Limit Value

The ammonium perchlorate in solid propellants is mixed in a rubber binder and would thus dissolve slowly. Toxic concentrations would be expected only in the immediate (within a few feet) vicinity of the propellant, if they occur at all. As noted in Table 7, the toxicity is relatively low (high maximum allowable concentration).

In summary, water pollution resulting from the operation of space shuttle vehicles is expected to be insignificant even for worst-case situations involving highly unlikely combinations of events. Even should such a situation occur, the effects are not persistent, i.e., the materials will disperse rapidly.

4. Noise

Source and Nature. The major source of noise associated with the space shuttle program will be the noise generated by the rocket engine exhaust flow during engine tests and launches. The nature of this noise may be generally described as intense, relatively short duration, and spectrally composed of predominantly low frequency energy.

The sound pressure levels anticipated during the launch of the space shuttle are presented in Table 8. These are the peak overall sound pressure levels (OASPL) in decibels (dB) referenced to (Re:) 0.00002 newtons per square meter (N/m^2)(0.00000042 psf) in the ground plane at the indicated distances from the launch site, and were computed using the currently available shuttle trajectory. The peak OASPL's are achieved only momentarily with the acoustic energy gradually increasing until the peak level is obtained and then gradually decreasing with flight time. Total duration of the noise level around this peak is two minutes or less. The peak frequency of the energy spectrum is also indicated in Table 8.

Table 8
PEAK OVERALL SOUND PRESSURE LEVEL ANTICIPATED
FOR SPACE SHUTTLE LAUNCH

Ground Plane Environment

(Duration - 2 minutes or less)

Distance from Launch Site Meters	Peak Overall Sound Pressure Level, dB Re: 0.00002 N/m^2	Octave Band Peak Frequency Hz
3,000 (10,000 ft.)	133	30
6,100 (20,000 ft.)	124	20
12,200 (40,000 ft.)	117	10
21,300 (70,000 ft.)	112	5

Extensive research on the effects of noise on man and structures has been conducted. These research studies have provided some means to establish realistic damage and annoyance criteria. The environmental effect of noise presented herein are provided for two regions surrounding the space shuttle launch site, controlled and uncontrolled areas. The controlled areas are those areas in which personnel and facilities are under direct government control, i.e., government-owned land and buildings. Uncontrolled areas are those regions which are not under direct government control.

Environmental Effects - Controlled Areas. Damage risk criteria for personnel in controlled areas are presented in Table 9. These criteria concern the physiological damage, i.e., hearing or body damage, which may result if the sound pressure level magnitude and duration in the indicated frequency range is exceeded. The criteria are considered valid for personnel with no protection for a single daily exposure. Space shuttle operational personnel within this area will be protected so that these limits will not be exceeded. Throughout the Apollo Saturn V Program, which generates frequencies and intensities of the same order as the space shuttle,

Table 9

DAMAGE RISK CRITERIA (a) FOR CONTROLLED AREAS[15]

(Physiological Damage -
No Protection Single Daily Exposure)

Frequency Range (Hz)	Duration (Minutes)	SPL, dB Re: 0.00002 N/m^2
1-20	-	- (b)
20-100	20	135
100-6,300	·8	125, dBA (c)

(a)Level and duration not to be exceeded or damage will result.

(b)No criteria has been developed for this area. Refer to reference (15), paragraph 7-3.1.2, page 7-41, for physiological effects of high intensity, low frequency acoustic energy.

(c)dBA; measured with an "A-weight" frequency network.

operational observers have been stationed 3,500 meters (11,500 feet) from the launch pad in a small enclosure, and emergency crews are located approximately 550 meters (1,800 feet) from the launch site in standard armored personnel carriers. None of these personnel have suffered injury.

Structural damage is possible with low-frequency, high-intensity noise. Therefore, structures within the controlled area will be designed to withstand the noise environment to which they are to be exposed.

Environmental Effects - Uncontrolled Areas. For these areas, a general noise exposure criterion of a maximum overall sound pressure level of 115 dB, Re 0.00002 N/m^2, for both man and structures has been established by the Launch and Landing Site Review Board. Normally, the acoustic energy which propagates into this region is of low frequency content, i.e., 100 Hertz and below. For acoustic energy in this frequency range, the 115 dB OASPL criterion is considered acceptable and has been substantiated by personnel and community noise exposure experienced during Saturn IB and Saturn V launches[15] and analysis of structural damage from low frequency noise.[16]

There is a general lack of information on the effects of noise (including sonic boom which is discussed in the next section) on wildlife.[17] It is evident that under certain conditions there may be some ecological effects, particularly when new noises enter wildlife habitats. At the same time, certain species seem to show adaptation to noise. The present state of knowledge in this area is incomplete. For the space shuttle test and launch and landing sites where high intensity noise is generated in the proximity of the vehicle during tests and launches, some wildlife may be affected. Based on experience with rocket engine tests and space launches to date, particularly during the Apollo program, no significant effect is foreseen.

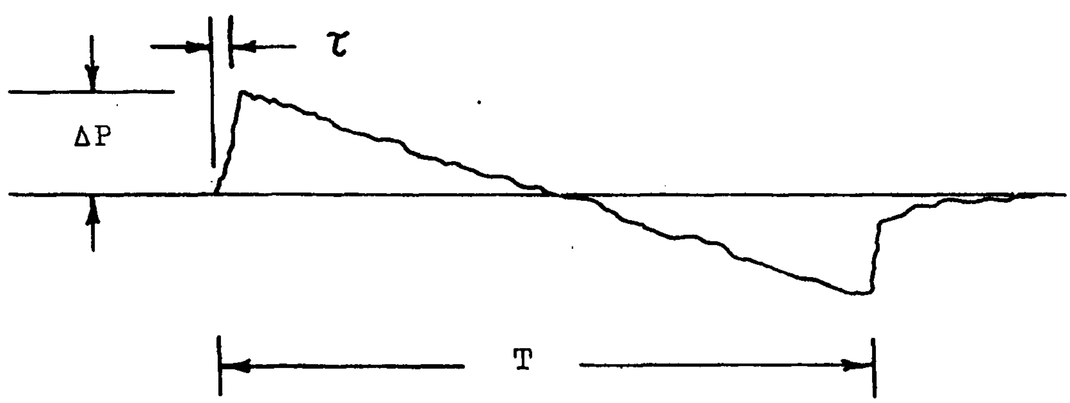
5. Sonic Boom

Source and Nature. As any body moves through the air, the air must part to make way for that body and then close itself once the body has passed. In subsonic flight, pressure signals (precursor waves which travel at the speed of sound) move ahead of the body to forewarn of its approach and the parting of the air and the passage of the body is a smooth process. In supersonic flight, precursor waves cannot precede the body; the parting process is abrupt. A bow shock wave parts the air which expands as it passes around the body and then a trailing shock wave recompresses the air as it closes behind the body. These waves travel through the atmosphere as pressure waves and, because of the abrupt noise they generate when passing an observer, are called sonic boom. This general pattern of bow shock wave, expansion region, and recompression shock is idealized as the N-wave signature commonly associated with the sonic boom. The phenomenon occurs for all supersonic flight. (See Figure 8 for nomenclature.)

The abruptness of the pressure changes is responsible for much of the concern about the sonic boom. It gives it the startling audibility and dynamic characteristics of an explosion, and even at great distances from the

Figure 8
CLASSIC N-WAVE ILLUSTRATION

The sonic boom disturbance, generated by the traverse of the shock wave created by supersonic flight across the surface of the ground, may be represented by the classical N wave as illustrated below.



Four parameters describe the N wave - rise time, τ; overpressure ΔP; period, T; and the impulse under the wave. These parameters, in turn, influence the reaction of people and structures to the disturbance. The characteristics of the N wave are a function of the aircraft (weight, shape, lift and volume), its operational characteristics (velocity, altitude, flight path angle, etc.) and the atmosphere through which it propagates (turbulence, temperature, winds, etc.). The near field disturbance for aircraft has a more complex shape caused by secondary shocks. As these disturbances propagate away from the source, however, the disturbance tends toward the classical N wave distribution.

vehicle where pressure levels produced are physically harmless, some public complaints are received. Sonic boom is likely to be of concern in shuttle operations because segments of the trajectories followed during ascent and descent involve supersonic flight within the atmosphere.

The characteristics of the shock pattern at its source are influenced by flight path characteristics, i.e., altitude, speed, angle of attack, flight path curvature, and accelerations either along or transverse to the flight path -- and body characteristics such as bluntness, weight, exhaust plume characteristics, and volume. The pressure signature that reaches the ground is subject to the additional factors of air turbulence, winds, and temperature variations of the atmosphere traversed by the pressure wave in addition to certain of the flight path characteristics.

Maneuvers associated with aircraft flight can result in focusing of the shock waves over small areas of the surface where overpressures may be greater than they would be for level flight. Focusing cannot be predicted by theory; however, flight test data for aircraft indicate that the pressures can be as much as two to five times higher in the focus zone than outside. Similar phenomena occur briefly during the boost phase of space launches.

Extensive knowledge of these factors developed by past studies of conventional supersonic aircraft provided much of the basic information required for prediction of the sonic boom pressure patterns (i.e., footprints) of the shuttle. It was necessary, however, to extend this basic knowledge by additional studies and experiments so that it would apply to the shuttle shape and the extremely high speeds and altitudes at which it operates.

To accomplish the additional studies required, a Sonic Boom Panel was formed within the Shuttle Aerothermodynamics Technology Working Group. The panel made extensive use of NASA's experience (over 20 years) in this field and successfully extended aircraft experience to the regime of shuttle operation. This success was shown by the prediction (and subsequent verification by measurement) of booms from an Apollo spacecraft.[18]

<u>Environmental Effects</u>. The extensive past work on the effects of sonic booms of varied characteristics and

intensities provides the guide to requirements for shuttle operations. A particularly useful reference is the authoritative summation of this work by the International Civil Aviation Organization (ICAO).[19] In its review of the effects of sonic booms, the ICAO found:

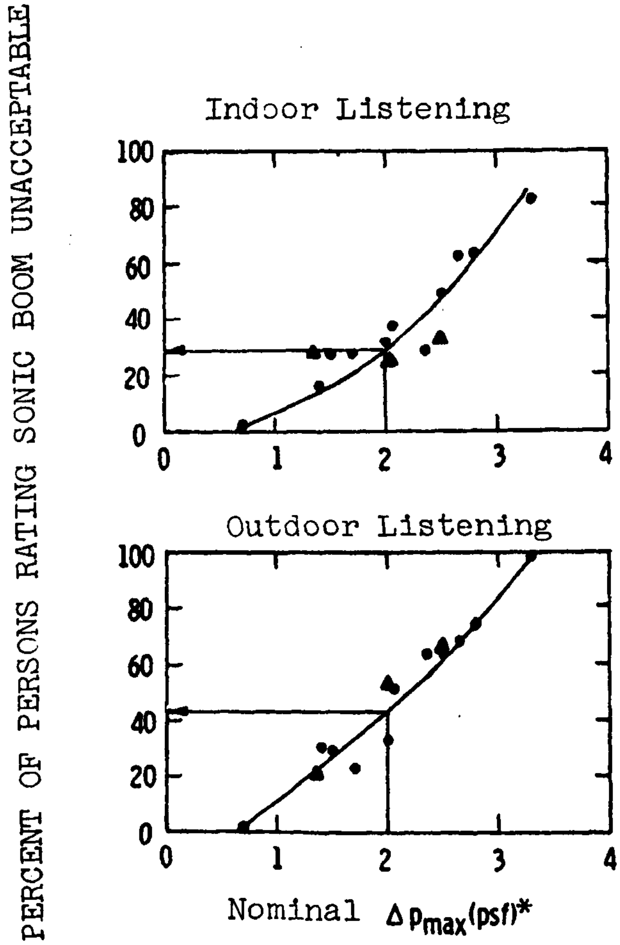
1. The probability of immediate direct injury to persons exposed to sonic boom is essentially zero.

2. The percentage of persons queried who rated sonic booms occurring 10 to 15 times daily as annoying increased with increasing overpressures. For overpressures less than about 24 newtons per square meter (N/m^2)(one-half pound per square foot), no one rated the boom as annoying; about ten percent considered 48 N/m^2 (one psf) sonic booms annoying and nearly all considered 144 N/m^2 (three psf) booms annoying (Figure 9).

3. Primary (loadbearing) structures meeting acceptable construction standards or in good repair showed no damage up to overpressures of about 950 N/m^2 (20 psf). Nonprimary structures such as plaster, windows and bric-a-brac sustained some damage at overpressures of from 48 to 144 N/m^2 (one to three psf).

4. Ground motions from sonic booms were found to be of the magnitude caused by footsteps.

Figure 9
SHUTTLE SONIC BOOM - ANNOYANCE



*One pound per square foot (psf) = 47.9 Newtons per square meter (N/M^2)

These results provide general criteria against which to consider sonic booms generated by the space shuttle. The annoyance criteria are conservative in view of the expected low frequency of shuttle flights (at most about one per week). The shuttle generates sonic booms at three different phases of its mission: ascent, booster reentry, and orbiter reentry. These are discussed separately in the following.

Ascent. The ascent phase will create the largest sonic booms of the mission as a result of two distinct effects. First, the overpressures that will be experienced over the ocean during supersonic ascent will be greater than those which might be expected from the shuttle alone because of the rocket exhaust plume. This plume increases the effective size of the vehicle and preliminary tests have indicated that the overpressures may be double those of the vehicle alone. Overpressures as high as about 290 N/m^2 (6 psf) may be expected at down-range locations, where the shock waves first reach the ocean's surface on the ground track (approximately 60 km (33 nautical miles) down range). Nominal overpressures would then diminish both down range (to less than 48 N/m^2 (1 psf) at 85 km (45 nautical miles) down range) and to either side of the ground track to lateral cutoff (to about 96 N/m^2 (2 psf)). Lateral cutoff occurs when the local gradient in the speed of sound causes the ray path to turn to a horizontal orientation (parallel to the ground). No sonic boom disturbance will occur between the launch site and the shock wave touchdown point. The approximate sonic boom footprint is shown in Figure 10.

The second effect is the focusing mentioned earlier caused by the longitudinal acceleration and pitchover maneuvers necessary for the vehicle to achieve orbit (Figure 11). This results from the accumulation and reinforcement of pressure waves in the focusing region. This region is a narrow area located along the touchdown line out to lateral cutoff about 75 km (40 nautical miles) to either side of the ground track (Figure 10).

With maximum overpressure levels as high as about 290 N/m^2 (6 psf) without focusing, and with focusing factors from two to five, the possibility of overpressures on the order of 1,440 N/m^2 (30 psf) cannot be ruled out at the center of the focal zone and 480 N/m^2 (10 psf) at lateral cutoff. The overpressures in the focal zone will be limited to a very narrow region approximately

Figure 10
ASCENT SONIC BOOM FOOTPRINT

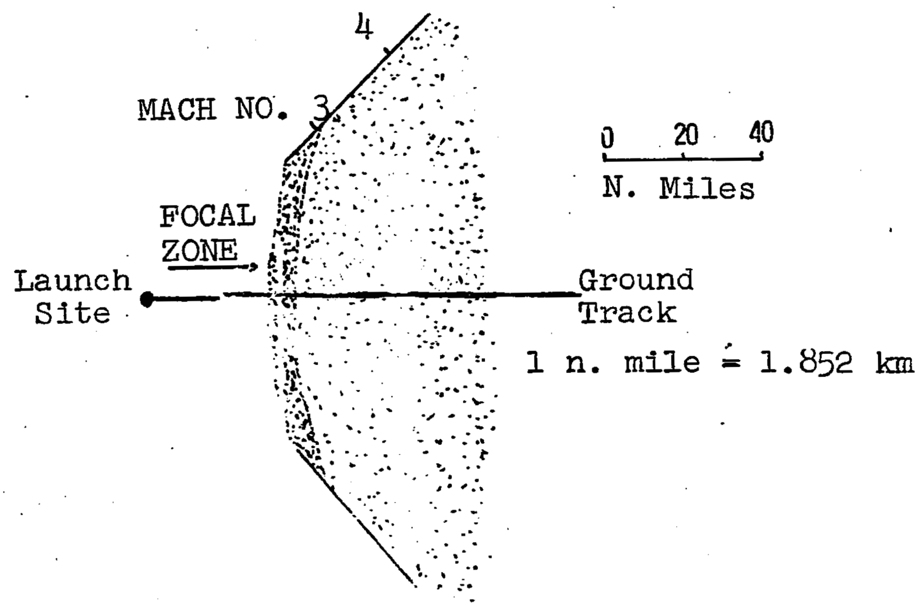
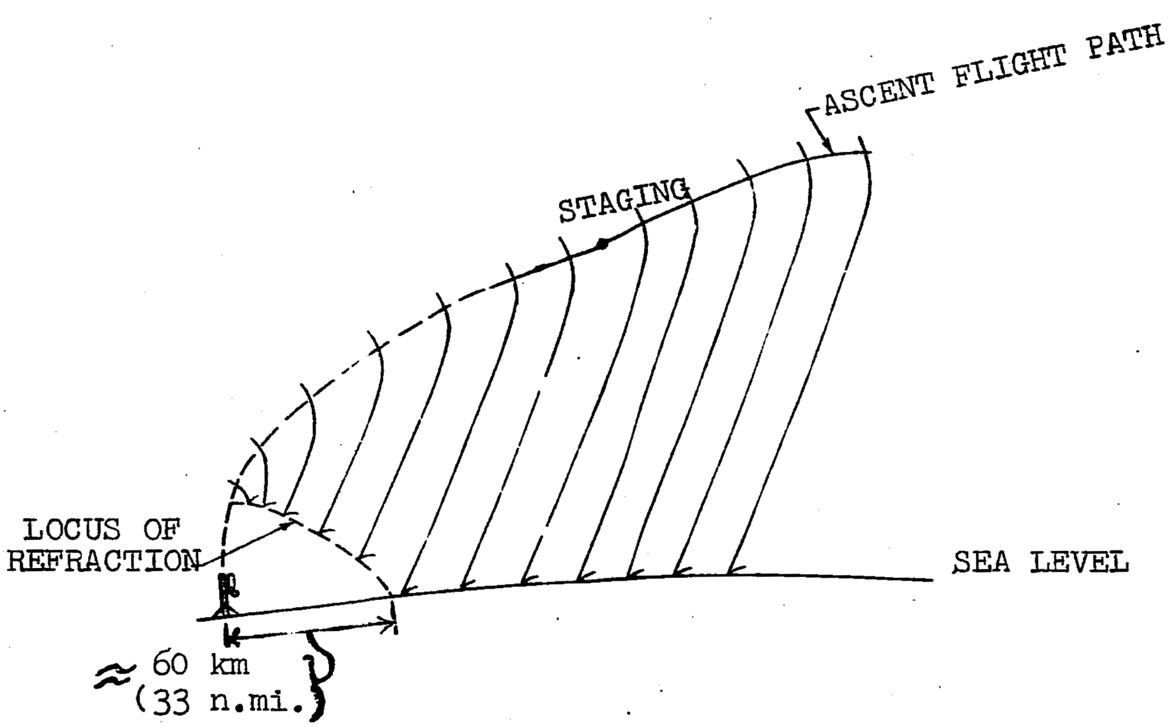


Figure 11
SONIC BOOM ASSOCIATED WITH ASCENT



300 meters (985 feet) wide at the ground track and even narrower out near lateral cutoff.

As far as is now known, this focused ascent boom appears unavoidable; this consideration contributed to the decision to employ a coastal launch site permitting the ascent sonic boom to occur over the ocean. The location of the focused boom will be predictable based on a given trajectory and existing wind conditions. Range Safety[20] designates a Launch Danger Zone for each launch. This is a sea area and air space measured from the launch point and extending down range along the intended flight azimuth. The size is based on the potential hazard to ships and aircraft. Helicopter and radar surveillance of this zone commences an hour before launch. Should the overpressure levels be considered harmful, the location of the focused boom will be included in the Launch Danger Zone. Ships in the area likely to be affected will be warned of impending launches as is the practice for current launches. Focused sonic booms occur during the supersonic boost phase of all launches, including Apollo launches, but have apparently gone unnoticed because they occur at sea.

Booster Reentry. After separation, the orbiter stage continues to climb and the booster reenters the atmosphere. During descent, the spent booster will generate a sonic boom striking the surface over an area from 280 to 370 kilometers (150 to 200 nautical miles) down range from the launch site. In this area, maximum overpressures rise to levels between about 96 and 144 N/m^2 (2 and 3 psf) similar to that experienced with current launch vehicles. This area of maximum overpressure coincides with the booster impact area which must be kept under surveillance to effect booster recovery as is done for the Apollo capsule recovery.

Orbiter Reentry. Based on extensive analytical work throughout the NASA and on an exhaustive experimental program conducted by the Ames Research Center, the sonic boom characteristics for the returning orbiter vehicle have been determined. Nominal overpressures during orbiter return will not exceed 24 N/m^2 (one-half psf) until the vehicle is within 650 km (350 nautical miles) of the landing site. Overpressures of 48 N/m^2 (one psf) are exceeded at about 185 km (100 nautical miles) from the landing site and the nominal maximum overpressures for any orbiter entry will not exceed 96 N/m^2 (2.0 psf).

Because of the infrequency of exposure of the general public to sonic boom in the past and to assess the impact of future shuttle operations, it may be helpful to relate the potentially annoying overpressures of 48 to 96 N/m^2 (1 to 2 psf) to more familiar occurrences. Such comparisons are valid for discussing annoyance, which depends chiefly upon peak overpressure and rise time. (However, the total impulse of each of these other phenomena is less than that of sonic booms, and the comparisons are therefore not necessarily valid for discussion of physical effects on structures.) Measurements taken inside automobiles when shutting a door have recorded overpressures of 170 to 190 N/m^2 (3.5 to 4.0 psf) for four-door sedans and station wagons and 360 to 410 N/m^2 (7.5 to 8.5 psf) for small compact cars. Overpressures of 72 to 96 N/m^2 (1.5 to 2.0 psf) have been experienced in the vicinity of sharp handclaps, with most people being able to generate 48 N/m^2 (1 psf) without great effort. The bursting of a toy balloon and the snapping of a tubeless automobile tire on the rim during initial inflation can generate overpressures of the same order as those for handclaps and auto door closings.

As noted by the ICAO[19], experiments and studies have not been able to relate overpressures of up to about

96 N/m^2 (2 psf) to damage in a definitive manner. The sonic boom characteristics associated with orbiter entry are, therefore, chiefly in the range of nuisance or annoyance. The real annoyance associated with these low levels of overpressure is questionable because the ICAO[19] conclusions were based on an estimated frequency of 10 to 15 booms per day. The shuttle would fly only about once each week, and sonic booms would be experienced even at this frequency only in the immediate area of the landing site (within about 75 km (40 nautical miles)). Areas farther away would not be expected to experience booms exceeding 48 N/m^2 (1 psf) more than a few times per year due to the varying approach angles to the landing site resulting from different orbital inclinations and return opportunities. Thunderstorms occur in the KSC area at higher frequency than would shuttle orbital reentries. With each thunderstorm containing nearly 200 claps of thunder on the average, residents in the vicinity of the KSC landing site hear thunderclaps more than two hundred times as often as they will hear sonic booms.

Sonic Boom over Ocean Areas. The recent ICAO report[19] states:

"Experience from Concorde test flights over water and many years of military flying over the sea, in particular near land where many ships and small boats are found, has not yielded any evidence of human disturbance by sonic booms at sea."

Sonic boom effects on marine life may be estimated from the pressure-wave intensity transmitted through the air-water interface. Because the speed of sound in water is approximately 4.5 times that in air, for flights at Mach numbers below about Mach 4.5, the transmitted pressure disturbance is subsonic in water and decays very rapidly with increasing depth.[21] For Mach numbers greater than 4.5 the shock wave is transmitted from the air into the ocean as a supersonic disturbance. In this case, the pressure field will propagate over longer distances and decay less rapidly than in the lower Mach number case. Nevertheless, the pressures would still be very small compared to hydrodynamic pressure. The subsurface pressure associated with sonic boom of 1,440 N/m^2 (30 psf) over-pressure is equivalent to the pressure from a 15 cm (6 inch) wave. Then, too, the "rough" surface of the ocean may well preclude this transmission effect, which has never been measured in the ocean. Marine life is expected to be unaffected.

6. Reentry of Spent Booster Rockets and Orbiter Propellant Tanks

Source and Nature. Both the spent booster and the orbiter propellant tank will reenter the atmosphere during the course of each shuttle mission. The spent solid rocket motor booster cases will land in the water between 185 and 370 kilometers (100 and 200 nautical miles) down range from the launch sites and be recovered and reused. For normal recovery, landing would be at low velocities through the use of parachutes. The open ocean recovery areas cannot be totally controlled (as if government property), and thus warnings of impending launches will be issued.[20] The same is true of areas between the launch site and recovery zone and within the recovery zone where impact could occur in an abnormal launch situation. Such impacts could conceivably be at higher velocity (e.g., with parachute failure) and include local explosion and fire involving previously unburned propellants.

The orbiter propellant tank is carried into orbit by the orbiter and is separated while they are in orbit. At an appropriate orbital position, the tank retrorocket will be fired initiating reentry. Reentry of the empty hydrogen/oxygen tank is characterized by moderate heating rates and decelerations at high altitudes. The heating and deceleration forces typically will cause the tank to break up into pieces of varying size, but will not ordinarily cause complete "burn-up." Therefore, a preselected remote ocean area will be specified for controlled reentry of the tank.

Environmental Effects. The major potential environmental effect of the hydrogen/oxygen tank reentry is from possible physical impact of reentry debris fragments. The risks are thought to be small; nevertheless, because of the size of the expendable hydrogen/oxygen tank (each empty tank will weigh about 31,800 kilograms (70,000 pounds), reentry will be controlled to a planned impact in an announced preselected remote ocean area at a specified time. The planning and controls which will be exercised under normal operations are expected to eliminate the probability of personal injury or property damage.

Should it be necessary to abort the mission prior to the attainment of orbit, the hydrogen/oxygen tank will be jettisoned to impact in a safe area. For an abort early in the flight, the orbiter will maneuver to return to the launch site after placing the tank on a trajectory to impact in a safe ocean or land area. Should this maneuver not be possible, the tank will be jettisoned on its launch trajectory and will impact down range. As in conventional U.S. space launches, down range impact locations will be predicted as a function of time from launch for the ascent phase and the trajectories chosen to avoid hazards in the event of system failure. For an abort in the later stages of the ascent, it will be possible to discard the hydrogen/oxygen tank in the same predetermined ocean location as for normal missions.

Should the propellant tank retrorocket fail, the tank will still undergo uncontrolled reentry and disintegration. The extent of this hazard has been considered and is small based on world-wide experience to date. However, the reentry control system will be designed so that the probability of reentry of the orbiter hydrogen/oxygen tank in this mode will be very small.

7. Land Use

Large areas of land surrounding the launch and landing site are required for supporting activities and to serve as a buffer between these activities and the surrounding community. At the Kennedy Space Center, and at Vandenberg

Air Force Base, maintenance of environmental stability has been stressed. For instance, at Kennedy citrus groves purchased by the Federal Government as part of the center are leased to growers by the Government and continue to produce well. Much of the Center has been designated a wildlife refuge and is maintained by the Department of the Interior. Discussions have taken place regarding the establishment of a National Seashore on much of the northern portion of the Center. This experience was included in the evaluation of candidate space shuttle launch and landing sites, and activation of the selected sites will continue to stress land-use patterns which maintain environmental values.

8. Social, Cultural, and Demographic Effects

An activity of the size of the space shuttle program could create change in communities affected by the various program elements. Communities surrounding the launch site would be affected more than others. As a result of the decision to use existing installations, no negative effects are expected. Specifics will be provided as necessary in appropriate institutional environmental impact statements.

9. Solid Wastes

The solid wastes generated by the program are associated with the construction of vehicles, equipment, and facilities. Most of the wastes are of relatively high value and are therefore recovered for recycling. Those which are not to be reused will be disposed of, along with sewage and other such wastes, in an environmentally acceptable manner appropriate to the site of the activity.

D. ALTERNATIVES

During the evolution of the space shuttle concept, alternative approaches have been under continuous consideration in terms of environmental, technical, and economic factors. The major alternatives to the development of the new space transportation system described here fall into three distinct categories. These are: (1) relying upon current launch vehicle types and their derivatives for the missions of the 1980's; (2) developing a two-stage hydrogen/oxygen-fueled shuttle, with both stages piloted in an aircraft-like manner; and (3) using liquid propellants in an unmanned booster stage. Environmental and other factors of significance to the consideration of these alternatives are discussed in the following paragraphs.

1. Current Launch Vehicles

The space shuttle can, when operational, economically replace the currently used Delta, Atlas, Titan III, and Saturn IB launch vehicles. To compare the continued use of such expendable launch vehicles with use of the reusable space shuttle, it is necessary to establish a mission model for each alternative which results in equal utility of orbital systems. This has been done for a number of different levels of activity[22][23] and utilized in extensive economic analysis.[24] Typically, the ratio of current expendable launches to shuttle launches for the same orbital utility is just over one, with most expendable vehicles being Titan III's (more than half of these requiring solid propellant stages).

The shuttle has a greater payload capability than the Titan III. However, for simplicity in comparing environmental effects, a given number of shuttle missions can be compared to the same number of expendable Titan III missions of which about 60 percent have a solid propellant stage. With this mission model, the environmental comparison is as follows:

(1) Atmospheric emissions of hydrogen chloride and alumimum oxide would be about five times less if current expendable vehicles were used.

(2) Sonic boom overpressures during ascent for the smaller expendable launch vehicles would be lower than for the shuttle because of the relationship between sonic boom and vehicle size. Booster reentry sonic boom would be comparable for both systems. Reentry sonic booms would be associated only with a few recoverable payloads if expendables were used.

(3) There would be an increase in potential orbital debris hazards resulting from the natural decay and reentry of the expended spacecraft and upper stages that would be

left in orbit if current expendable vehicles were used. Reentry control of all of this material is not considered technically feasible, even at greatly increased costs. The orbiter propellant tank of the shuttle, the only expendable element of the system, will be controlled to reenter and be disposed of in a preplanned remote ocean area at a predetermined time. Further, the shuttle is designed to recover objects from space and can reduce hazards by removing space debris before it reenters.

The absolute environmental costs of the shuttle are transient and small, as shown in the preceding sections. Of far greater consequence are the lower costs of resources, both natural and fiscal, associated with the space shuttle program. Because all elements of the shuttle (except the orbiter propellant tank) and many payloads are planned to be reusable, one-half to one-third as much structural material will be expended by the shuttle for each launch as compared to a Titan III launch. Far smaller relative amounts of valuable auxiliary materials such as copper, gold, and silver will be expended by the shuttle and its recoverable payload than Titan III and its generaly expendable payload.

Lower fiscal costs have been conclusively demonstrated in economic studies. Appendix A contains a typical example of the many mission models used to test the economics of the shuttle program. This example assumes a mission model of some 580 missions over the 12-year period of 1979-1990, roughly the same rate as for all U.S. missions over the past few years. For this case, development and utilization of the space shuttle results in savings of over $5 billion after amortization of total development of the shuttle and investment in vehicles and facilities.

The larger potential savings in resources, both natural and monetary, together with the absence of permanent environmental impacts, clearly demonstrate the overall cost-effectiveness of the shuttle compared to continued use of the current expendable vehicles.

2. Hydrogen/Oxygen Reusable Flyback System

The design concept to which the studies,* initiated in 1970, were originally addressed was a very large, fully reusable system consisting of piloted booster and piloted orbiter stages, with all propellants carried internally. The concept would have required major technological advances with concommitant technical risks; the development cost (excluding facilities) of such a system would have been

*The studies referred to in this section are listed in Appendix C.

over $10 billion.

Environmental effects of this concept would have been quite small, as noted in the first draft environmental impact statement released in March 1971. The hydrogen/oxygen propellant mixture burns quite cleanly to produce only water vapor. Such a system would impose a sonic boom pattern very similar to that expected from the currently proposed system during ascent with equal or greater overpressures expected. Booster return over-pressures might be ameliorated because of booster maneuverability; orbiter overpressures would be higher because of the much larger orbiter size. No external tanks would be utilized, and thus the controlled entry of such tanks would not have to be considered.

The high total development cost and technical risks implied annual development costs as high as $2 billion during the later 1970's. Studies were thus initiated to determine if other, less costly but still cost-effective and environmentally benign shuttle configurations could be developed.

3. Evolution to the Current Shuttle

Studies* subsequent to those of the initial two-stage

*The studies referred to in this section are listed in Appendix C.

flyback concept showed that the size of the system and its development cost could be greatly reduced through the use of an external expendable liquid-hydrogen tank for the orbiter, with a small increase in operating costs per launch. Further study showed that additional cost savings and technical advantages in the development program would accrue if both the liquid-oxygen and liquid-hydrogen for the orbiter were carried in an external tank jettisoned from orbit. This change permitted the orbiter vehicle to be significantly smaller, thereby simplifying development and reducing substantially the development and procurement costs at the expense of some additional increase in the recurring cost per flight.

With these modifications, shuttle development costs were estimated to be between seven and eight billion dollars. Environmental impact was essentially the same as that of the more expensive, initial two-stage flyback concept except for the new element of having to dispose of a hydrogen/oxygen propellant tank from orbit. It was determined that the tank could be equipped for controlled reentry to a remote ocean area at a predetermined time, and that no significant environmental hazard would exist.

Additional studies indicated that further reductions in orbiter development costs could only be achieved at the expense of compromising the objectives of providing a new flexible orbital capability at low operational costs. Thus, attention was turned to reducing development costs of the booster. Consideration of the reduced-size orbiter with external propellant tanks opened the possibility that an unmanned ballistic booster could be effectively employed, a possibility earlier precluded by the larger orbiter concept with internal tanks.

The ballistic unmanned boosters studied included both pressure-fed and pump-fed liquid propellant boosters and solid propellant boosters. The two liquids compared as follows:

(1) In the pressure-fed system, the engine would have been a major new development. In the pump-fed system, it would have been a modified F-1 engine (the engines used in the Saturn V booster).

(2) New manufacturing techniques would be required for the pressure-fed booster; conventional techniques developed for Saturn would be used for the pump-fed booster.

(3) Major modification of facilities would be required for the pressure-fed booster; to a large extent,

existing facilities could be used for the pump-fed booster with minor modifications.

(4) The stiff, thick walls of the pressure-fed booster could withstand a moderately high impact velocity, and thus it lent itself to booster recovery. Recovery of the thin-walled, pump-fed booster appeared of much higher risk.

(5) Environmental effects of both liquid systems would have been the same.

It was concluded that the pump-fed system had cost advantages and lower technical risk in all aspects except the recovery risk, which appeared large. Of the two liquids, the pump-fed concept was deemed more advantageous in spite of the need to develop complex recovery systems.

The pump-fed liquid series burn* concept compares to the solid rocket motor parallel burn** concept as follows:

(1) The liquid booster requires thrust vector control for control during boost phase. The solid does not,

*Series burn - the orbiter engines are ignited after booster shutdown and separation.
**Parallel burn - the orbiter engines are ignited on the pad and burn continuously through the boost phase and on into orbit. The booster is ignited on the pad and boosts to burnout, where it separates and reenters.

as the orbiter engines would be firing simultaneously and provide sufficient control.

(2) For abort, the series-burn liquid system would be conventional, as for Apollo. The solid system requires a nondestructive thrust termination system. Both systems would require an escape rocket for intact abort of the orbiter.

(3) Acoustic noise and vibration level would be higher outside the orbiter payload bay for the solid, but manageable.

(4) Providing recovery would entail major developmental risks for the liquid but would be simpler for the solid. More importantly, the net cost of losing a liquid booster would be perhaps 10 times greater than losing a solid, jeopardizing the ability of the shuttle to attain low costs of recurrent operations.

(5) The solid booster system would be about 45,400 kilograms (100,000 pounds) lighter than the liquid booster. Development costs of the solid are estimated to be about $700 million lower than those of the liquid.

(6) Environmental effects for both liquid and solid systems were about the same with one exception, propellants and their exhaust products. The liquid booster would use RP, a kerosene-like rocket propellant, and liquid oxygen,

and its exhaust products would be chiefly carbon monoxide, water vapor, and carbon dioxide, along with smaller quantities of hydrocarbons and ammonia. Propellants for, and emissions from, the solid motors have been detailed in a preceding section, with the chief emissions being hydrogen chloride, carbon monoxide, water vapor, and aluminum oxide.

In summary, it was determined that, of the unmanned ballistic recoverable boosters, the solid booster with parallel burn would give the lowest development cost, less capital risk per flight, and lower technical risk of development. Environmental effects would be minor, although it would be necessary to impose additional constraints on launch associated with the likelihood of rain falling through the launch exhaust cloud and scrubbing out the hydrogen chloride in solution as hydrochloric acid. These constraints are in addition to normal launch constraints imposed by wind shears and other factors. The additional constraint has been deemed acceptable to the meeting of program objectives. These factors led to the selection of the solid-rocket-motor booster, parallel-burn concept for the space shuttle.

The possibility of reducing total systems costs through reducing the size of the payload bay in the orbiter from 4.6x18 meters (15x60 feet) to 4.3x14 meters (14x45 feet) and reducing the payload capacity for a due east launch from 29,500 kilograms (65,000 pounds) to 20,400 kilograms (45,000 pounds) was considered. The additional cost savings were estimated to be only about $70 million in the development program, less than 1½ percent of the total of about $5 billion. Furthermore, the orbiter with the smaller payload compartment was unable to accommodate about 10 percent of the projected civil missions and about 37 percent of the projected military missions for a typical mission model for the period 1979-1990. Therefore, the smaller shuttle would have required retention of large expendable boosters in the U.S. launch vehicle inventory for that period to handle the larger payloads. Environmental effects would be essentially the same for both sizes of orbiter. However, the retention of expendable vehicles in the case of the smaller orbiter would imply continued expending of certain mineral natural resources and a higher total cost for U.S. space activities.

E. THE RELATIONSHIP BETWEEN THE LOCAL SHORT-TERM USES OF THE ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

The environmental effects of the shuttle are localized and of relatively short duration. Although these effects will limit the use of the immediate environment for the period immediately before and after a launch, there is no foreseeable adverse effect on long-term environmental productivity. On the contrary, the space shuttle has great potential for improving the management of the earth's environment and natural resources.

The space shuttle can provide the means for launch and recovery of environmental and resource satellites expected to be operational during the 1980's for various users such as the National Oceanic and Atmospheric Administration and the Departments of Interior and Agriculture. In addition, the shuttle will permit continuing research and development on improved systems by NASA and the user agencies. Scientific space shuttle missions would investigate the interactions of the earth's environment with the space environment and the sun. The benefits of these programs would ultimately be measured in terms of greater understanding of the processes that govern the weather, improved prediction of weather and especially weather hazards, monitoring and control of pollution, and capability for inventory and management of the earth's resources on a national and even a global scale. Finally, productivity of the space systems themselves would be greatly increased through the ability afforded by the shuttle to recover, maintain, and reuse them.

With the shuttle in being, space flight's contribution to man's environment will mature and become one of the main tools in measuring, monitoring, and managing earth's conditions and natural resources. In summary, this Nation's short-term investment in the space shuttle program will result in a long-term improvement of the global environment for future generations.

F. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF NATURAL RESOURCES

The space shuttle orbiter returns to earth and lands like an aircraft and the booster solid rocket motors are recovered and reused. All structural elements of the shuttle are retrievable with the exception of the external hydrogen/oxygen tank which is jettisoned in flight and disposed of in a remote ocean area. This tank is constructed of aluminum and weighs approximately 31,800 kilograms (70,000 pounds). When the shuttle is fully operational, up to 50 of these tanks will be expended each year. This expenditure of about 1.6 million kilograms ($3\frac{1}{2}$ million pounds) of aluminum per year in the 1980's may be compared to the annual U.S. production of nearly 3.6 billion kilograms (8 billion pounds) in 1969.

The propellants used by both orbiter and booster are irretrievable. The orbiter consumes 558,000 kilograms (1,230,000 pounds) of LOX and 95,300 kilograms (210,000 pounds) of H_2 per flight. It may also consume 3,700 kilograms (8,150 pounds) of N_2H_4, 8,500 kilograms (18,700 pounds) of N_2O_4, 1,820 kilograms (4,000 pounds) of JP-5, and approximately 68 kilograms (150 pounds) of helium on each flight. The orbiter also utilizes solid rocket motors for flight maneuvering and these motors consume 18,200 kilograms (40,000 pounds) of solid propellants each mission. The solid rocket booster consumes approximately 1,090,000 kilograms (2,400,000 pounds) of solid rocket propellant for each launch.

Propellants will also be consumed in ground testing of the various propulsion elements. Approximate totals for all development, qualification, and major ground tests over the 6-year development period are as follows:

LOX - 164 million kilograms (362 million pounds)

LH_2 - 33.8 million kilograms (74.5 million pounds)

Solid Rocket Propellant - 7.7 million kilograms (17 million pounds)

N_2H_4 - 449 thousand kilograms (989.3 thousand pounds)

N_2O_4 - 206 thousand kilograms (454 thousand pounds)

Natural gas is currently used to produce liquid hydrogen for space missions. About 94 million cubic meters (3 1/3 billion standard cubic feet) of natural gas per year would be required to provide the liquid hydrogen for a launch rate of 50 shuttle missions per year in the 1980's.

This may be compared to the current production of about 455 billion cubic meters (16 trillion standard cubic feet) and that expected for 1980 of about 710 billion cubic meters (25 trillion standard cubic feet). Alternate liquid hydrogen production methods can be developed if natural gas resources are inadequate to the total national demand. Other materials used include glass, nickel, chromium, lead, titanium, zinc, copper, and very small quantities of silver, mercury, gold, and platinum. The ability to recover and reuse booster and orbiter avoids the loss of any significant quantities of these materials.

G. COMMENTS ON ENVIRONMENTAL STATEMENT FOR SPACE SHUTTLE PROGRAM

Comments on the first draft environmental statement for the space shuttle program (released March 1, 1971) were requested from CEQ, OMB, EPA, DOT, DOD, and the State Department. Comments on that draft were received only from EPA. Comments on the second draft (released April 19, 1972) were requested from CEQ, EPA, DOD, DOA, DOT, HEW, HUD, DOI, DOC, OMB, State, AEC, NSF, and FPC. Responses were received from DOA, DOT, DOD, DOC, DOI, HUD, HEW, AEC, and EPA. All responses are included in Appendix D.

A number of commenting agencies (HUD, DOI) suggested that effects local to the launch and landing sites be covered in more detail. Local effects will be described in appropriate institutional environmental statements to be issued and circulated for comments as required by CEQ guidelines.

Two agencies (DOT and DOC) raised questions about the means to be used to warn mariners who might otherwise be in the zone of focused sonic boom at the time of space shuttle launches. Current NASA practice includes a highly effective monitoring and warning system deemed suitable for future shuttle operations. This final statement includes a brief description of that system and a reference to the appropriate range safety document.

The Environmental Protection Agency suggested that the final statement should indicate the relationship between the concentrations of solid rocket motor exhaust products in the atmosphere and appropriate National Primary and Secondary Air Quality Standards. The information has been added to the extent that it is available. Peak concentrations of carbon monoxide are well below the applicable standard for one-hour exposure. While peak concentrations of aluminum oxide exceed the 24-hour standards for particulates, the exposure would be for only a few minutes, and thus the 24-hour exposure would be below the applicable standard. National standards have not yet been promulgated for hydrogen chloride.

Programs of research and monitoring are suggested (by EPA, DOC, and DOI) to confirm the theoretically predicted atmospheric effects of both launch- and reentry-induced constituents. Such programs are already in being and will be continued as necessary. For example, NASA is participating with the DOT (and others) in the Climatic Impact Assessment Program (CIAP) determining the effects of minor, upper atmosphere constituents upon climate. NASA has its own program to determine the distribution and effects of minor, upper atmospheric constituents and provides program results to the other agencies.

The recent Apollo 16 launch afforded the opportunity to test experimentally the mathematical model used to predict low altitude concentrations of emittants from the rocket exhaust, and the results are presently being analyzed. Such tests of the mathematical model will continue and the model will be updated and improved as test results warrant. This is part of a comprehensive program to better assess the diffusion in the atmosphere of rocket engine exhaust emissions and their effects.

A research program, both theoretical and experimental, is being conducted to determine the generation, transport, and life time of chemical compounds and ions produced by the shock wave and through ablation during orbiter reentry. Sufficient information is available to indicate that such disturbances in the upper atmosphere are highly local and short lived and that no adverse consequences are likely. However, the program will be pursued to its conclusion to ensure that no factors have been overlooked.

Finally, grants to the Florida Technology University and the Florida Institute of Technology have been made to determine the baseline ecology of the Kennedy Space Center environs. The ecological impact relative to this baseline of the actions taken during the space shuttle program will be carefully monitored.

APPENDIX A

SPACE SHUTTLE ECONOMICS*

1. Justification

The justification of the space shuttle is not based on the details of space shuttle economics alone. It is a fact that the shuttle is a good investment and will make possible significant savings in future space operations. But the fundamental reason for developing the space shuttle is the necessity to have a means for routine, quick reaction and economical access to space and return to earth in order to achieve the benefits of the scientific, civil, and military uses of space that will be important in the decade of the 1980's and beyond. The space shuttle program is also the lowest cost approach for providing a continuing useful capability for manned space flight and for maintaining a clear U.S. presence in space.

2. Funding Requirements

a. The development cost for the space shuttle is now estimated to be $5.15 billion.

b. The additional investment costs for procurement of production flight hardware and facilities is estimated at about $1.3 billion, on the reasonable assumption that the initial inventory will include: 3 production orbiters, 2 refurbished orbiters, and the initial production boosters.

c. The total investment, therefore, required to develop the shuttle and procure flight hardware and provide facilities will be approximately $6.45 billion.

3. Implied Future Commitments

a. The full development of the shuttle, the initial investment required, and its subsequent operation, together with a continuing well-balanced program in science, applications, and aeronautics, can be supported at an essentially constant total NASA budget level, i.e., about $3.4 billion in 1971 dollars.

b. The peak annual total funding level required for the shuttle during the development period is estimated at about $1.2 billion. As stated above, this will not require an increase over the current total NASA budget level.

*See reference (24) for a complete analysis of shuttle economics.

4. Relation of Shuttle Funding to Other Space Program Funding

a. There has been some confusion on funding levels required for the shuttle because some people have incorrectly counted the cost of future satellites and other payloads and mission support in future years as a part of the development or investment costs of the space shuttle system. In this way, figures of $10 billion or more have been arrived at as the "true" cost of the shuttle system. This line of reasoning seems to assume that future satellites and payloads would be put in space only because we will have a shuttle, or would be put in space at a rate which is unreasonably high because we have the shuttle, thereby leading to annual budget levels far greater than current levels.

b. The facts are:

(1) The decision to develop the shuttle does not entail an increased level of future expenditures for the satellites and payloads it will carry or for conducting shuttle missions.

(2) The scientific and civil and military applications missions the shuttle will perform will be the same ones that would otherwise be launched by expendable boosters, although the additional capabilities of the shuttle will mean that many missions will be performed differently and more effectively.

(3) After development, the cost of performing these missions will be less with the shuttle than without, because the shuttle will be a more economical launch vehicle and because payload costs can be reduced by reuse and redesign.

(4) Economical use of the shuttle, including mission costs, is achievable with total annual budgets for space at substantially the current levels. Numbers of the order of $10 billion or more, if correct at all, relate to expenditures that would be spread over a long period of time and which need not exceed the present annual levels.

5. Illustration of Expected Economies through Use of the Shuttle

a. A realistic combined mission model for NASA, DoD, and other users, one of several that has been studied, 3

calls for some 580 missions over a 12-year period (1979-1990), an average of less than 50 missions per year. Models like this are not approved plans, but provide assumptions to test the reasonableness of developing the space shuttle from an economic standpoint.

b. In this model, launch and launch-related costs using existing conventional vehicles would be some $13.2 billion over those 12 years. Using the shuttle, the total launch costs, including procurement of replacement boosters, drop to about $8.1 billion, an economy of some $5.1 billion.

c. The payload development and procurement costs for this mission model would, for conventional launches, run about $35.1 billion over these 12 years divided between NASA, DoD, and other agencies. Because of payload reusability, design simplification, and lower risk factors, the 580 shuttle missions would have payload costs of about $26.8 billion. This is an economy of another $8.3 billion.

d. Therefore, the assumed 12-year flight program can be carried out with the shuttle about $13.4 billion cheaper than without, an average saving of over $1 billion per year.

e. The average total annual cost for launch and payloads in the assumed mission model is about $4.0 billion without the shuttle and about $2.9 billion with the shuttle. These levels are compatible with the current levels of the total space budgets for NASA, DoD, and other agencies.

6. <u>Shuttle Amortization over 580 Missions in 12 Years</u>

a. Investment in space shuttle, including initial inventory, as in Item 2 above (details shown below):	$6.45 billion
(1) Development, test, and procurement of 2 orbiters and 2 boosters	(5.15)
(2) Refurbish 2 orbiters and procure 3 more, including engines, and initial production boosters	(1.0)
(3) Facilities for development, test, and launch capability	(0.3)

b. Additional investments required to fly mission model assumed in Item 5 above: $1.6 billion

c. Total development and investment 1972-1990 (sum of Items 6a and 6b): $8.05 billion

d. Net reduction in cost of 580 missions because of shuttle operations, as in Item 5d above: $13.4 billion

e. Twelve-year benefit saving realized from shuttle investment (Item 6d minus 6c): $5.35 billion

f. Thus, even if the space programs of NASA, DoD, and other agencies terminated in 1990, the shuttle would have more than paid for itself by then.

7. Additional Points

a. The specific missions that justify the shuttle are those that could and would otherwise be justified on their own merits with conventional launch vehicles; the shuttle makes them more effective and less expensive.

b. The shuttle is self-sufficient; it does not require a space station in order to meet the good investment criterion, or to conduct useful manned missions in earth orbit.

c. Without the shuttle, the U.S. will have no program of manned space flight after 1973.

8. Conclusion

Even though the primary justification for the space shuttle is not economics, for mission models at current space budget levels and similar to those now in effect the shuttle investment will be returned with billions to spare. If, as is likely, new useful and economically beneficial mission possibilities open up during the 1980's because of the routine and quick access to space the shuttle provides, the investment will be returned many times over.

APPENDIX B

REFERENCES

(1) Smith, J. R., "Overview of Titan III Solid Rocket Motor Toxic Hazard," Aerospace Corp., El Segundo, California, Feb. 1972

(2) Smyth, Henry F., Jr., "Military and Space Short-Term Inhalation Standards," Archives of Environmental Health, Volume 12, April 1966, pages 488-490

(3) Dumbauld, R. K., and Bjorklund, J. R., "Hazard Estimates for Selected Rocket Fuel Components at Kennedy Space Center," NASA CR 61358, May 5, 1971

(4) Craig, R. A., "The Upper Atmosphere - Meteorology and Physics," Academic Press, New York, 1965

(5) Valley, S. L. (Editor), "Handbook of Geophysics and Space Environments," Air Force Cambridge Research Laboratories, Office of Aerospace Research, 1965

(6) Dumbauld, R. K., Bjorklund, J. R., Cramer, H. E., and Record, F. A., "Handbook for Estimating Toxic Fuel Hazards," NASA CR 61326, April 1970

(7) Cramer, H. E., Dumbauld, R. K., Tingle, A. G., and Bjorklund, J. R., "Quantitative Assessment of the Environmental Effects of Rocket Engine Emissions During Space Shuttle Operations at Kennedy Space Center," Report No. GCA TR-72-8-G, GCA Corp., Feb. 7, 1972

(8) "Guides for Short-Term Exposures of the Public to Air Pollutants, II. Guide for Hydrogen Chloride," Committee on Toxicology of the National Academy of Sciences - National Research Council, Washington, D.C., Aug. 1971

(9) National Primary and Secondary Ambient Air Quality Standards, Environmental Protection Agency, Part II of Federal Register, Vol. 36, No. 84, April 1971 (Updated Nov. 1971)

(10) "Threshold Limit Values of Airborne Contaminants," American Conference of Governmental Industrial Hygienists, 1971

(11) Man's Impact on the Global Environment: Assessment and Recommendations for Action, Report of the Study of Critical Environmental Problems (SCEP), the MIT Press, Cambridge, Mass., 1970

(12) Stewart, John C., Thiokol Chemical Corporation, Reaction Motors Division Memorandum to NASA/Lewis Research Center/H. Bankaitis, Subject: June 17, 1967, Firing of 260-Inch Motor SL-3 at Dade County, Florida - Air Samples from Exhaust Cloud - Report of Findings under Contract to U.S. Air Force, Nov. 2, 1967

(13) Kellogg, W. W., "Pollution of the Upper Atmosphere by Rockets," Space Science Reviews 3 (1964), pages 275-316

(14) McKee, J. E., and Wolf, H. W., "Water Quality Criteria," The Resources Agency of California, State Water Quality Control Board, Pub. #3-2, 1963

(15) Wilhold, G. A., Jones, J. H., et al., Chemical Rocket/Propellant Hazards, Vol. 1, General Safety Engineering Design Criteria, CPIA Publication 194, Oct. 1971, Chap. 7, "Acoustic Energy Hazards"

(16) "Launch Noise Criteria for the Prevention of Building Damage," Langley Research Center In-House Paper, July 1962

(17) NRC 500.1, "Report to the President and Congress on Noise," U.S. Environmental Protection Agency, Washington, D. C., 20460, Dec. 31, 1971

(18) Hicks, R. M., Mendoza, J. P., and Garcia, F., Jr., "A Wind Tunnel - Flight Correlation of Apollo 15 Sonic Boom," NASA TMX-62,111, Ames Research Center, Moffett Field, California 94035, Jan. 28, 1972

(19) Report of the Sonic Boom Panel of the International Civil Aviation Organization (ICAO), Oct. 1970

(20) Range Safety Manual AFETRM 127-1, Vol. I, Headquarters Air Force Eastern Test Range, Air Force Systems Command, United States Air Force, Jan. 1, 1969

(21) Malcolm, G. N., and Intrieri, P. F., "Shock Waves Produced in Water by Sonic Boom Over Pressures," paper for the AIAA 5th Fluid and Plasma Dynamics Conference, Boston, Mass., June 1972, Ames Research Center, NASA, Moffett Field, California 94035

(22) Integrated Operations/Payloads/Fleet Analysis Final Report, Volume II: Payloads, The Aerospace Corp. Report No. ATR-72 (7231)-1, Vol. II, Aug. 1971

(23) Integrated Operations/Payloads/Fleet Analysis Final Report, Volume V: Mission, Capture and Operations Analysis, The Aerospace Corp. Report No. ATR-72 (7231)-1, Vol. V, Aug. 1971

(24) Economic Analysis of the Space Shuttle System, Volumes 1-3, MATHEMATICA, Inc., Jan. 31, 1972

APPENDIX C

List of Study Contracts

Technical documents have been delivered to NASA in connection with the Space Shuttle system, engine, and solid rocket motor study contracts listed below:

Contract	Subject	Contractor
NAS 9-10960	Phase B Definition Study, Space Shuttle Program	North American Rockwell Corp.
NAS 8-26016	Phase B Definition Study, Space Shuttle Program	McDonnell Douglas Corp.
NAS 9-11160	Phase A/B Definition Study, Space Shuttle Program	Grumman Aerospace Corp.
NAS 8-26362	Space Shuttle Definition Study	Lockheed Aircraft Corp.
NAS 8-26341	Space Shuttle Definition Study	Chrysler Corp.
NAS 8-28200	Pressure-Fed Booster	Chrysler Corp.
NAS 8-28218	Pressure-Fed Engines	TRW, Inc.
NAS 8-28217	Pressure-Fed Engines	Aerojet Liquid Rocket Company
NAS 8-28431	Solid Rocket Motors	United Technology Center Division of United Aircraft Corp.
NAS 8-28430	Solid Rocket Motors	Thiokol Chemical Corp.
NAS 8-28429	Solid Rocket Motors	Lockheed Propulsion Corp.
NAS 8-28428	Solid Rocket Motors	Aerojet Solid Propulsion Company
NAS 8-26186	Space Shuttle Main Engine Phase B Definition	Pratt and Whitney

Contract	Subject	Contractor
NAS 8-26187	Space Shuttle Main Engine Phase B Definition	Rocketdyne Division, North American Rockwell Corp.
NAS 8-26188	Space Shuttle Main Engine Phase B Definition	Aerojet Liquid Rocket Company

APPENDIX D

RESPONSES TO DRAFT ENVIRONMENTAL STATEMENT
FOR SPACE SHUTTLE PROGRAM

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR

EPA-74

October 5, 1971

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and
Space Administration
Washington, D.C. 20546

Dear Mr. Cushman:

Our agency has completed the technical review of the draft environmental impact statement on the NASA Space Shuttle Program.

In general, we believe that the most serious possibility for adverse environmental impact would occur in the event of an operational mishap leading to:

1) Chemical contamination of surface water.

2) Radiological contamination of surface water or the atmosphere.

We enclose our detailed comments on these and other concerns. If you have any questions, please contact Mr. Jack Anderson of our office.

Sincerely,

George Marienthal

George Marienthal
Acting Director
Office of Federal Activities

Enclosure

Comments on the (Draft) Environmental Impact Statement on the NASA Space Shuttle Program

The draft statement should be expanded to include a complete discussion of the various types of credible mission accidents and an estimate of the probability of occurrence of each. The discussion should be directed toward an assessment of the possible adverse environmental consequences inherent in such accidents and how these consequences vary depending on where in the flight procedures they occur (i.e. during the launch, at high altitudes, during orbital operations, during reentry or landing phases).

Two possibilities which deserve particular attention are:

- Contamination of surface water by the intentional dumping or accidental spillage of unburned jet fuel accompanying a mission abort or reentry accident. The statement should include information concerning:

1) The types of fuels likely to be involved;

2) The probable environmental fate of such fuels.

3) The nature of the chemical reactions and properties of resulting chemical compounds produced when fuels contact either salt or fresh water, particularly as these compounds affect water quality and marine life.

4) The bodies of water likely to be affected.

A similar discussion should be included on any other nonradioactive materials which are likely to be dispersed by accident or design and are on board shuttle craft or boosters in sufficient quantities to pose an environmental hazard.

- Radiological contamination of air or surface water by the accidental release of radioactive materials which could occur as a result of the rupture of any vessel containing radioisotopes. Any type of equipment which contains significant quantities of radioactive material, whether it be a nuclear generator or experimental device, could present a hazard. The environmental impact statement should provide details on the following:

1) Types and nature of all equipment to be used in the space shuttle program containing any type of radioactive material.

2) The source terms for radioactive material. (i.e. the types and quantities of isotopes; physical state(s) of material(s); modes, energies, and half-lives associated with radioactive decay.

3) The probable environmental fate of any radioactive material released based on:

   a) Physical form of material(s) released as a function of the type of accident.

   b) Amounts of material involved.

   c) Point of release (i.e. geographical location and altitude).

   d) The meteorological or hydrological characteristics of the region.

4) Estimated dose rates or exposures both on and off-site under "average" and "worst case" meteorological conditions. Discussion should include a complete description of monitoring, facilities, operational plans, personnel and their responsibilities; system performance capabilities and limitations;

5) Accident contingency and radiological safety plans including a description of the organization, operation, objectives, and the response capabilities of all involved health agencies in addition to decontamination procedures to be employed in the event of a radioisotope fuel spill.

In order to evaluate the total environmental impact of the project, some discussion of the methods and techniques of generation of liquid hydrogen from natural gas should be included in the impact statement. Do these processes involve any venting of CO, CO_2, or other gases to the atmosphere and in what quantities?

DEPARTMENT OF AGRICULTURE
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20250

May 19, 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and
Spcae Administration
Washington, D.C. 20546

Dear Mr. Cushman:

Thank you for allowing us to review the draft environmental impact statement for the NASA Space Shuttle Program. We have no comments.

We note that questions of land use cultural, social, and demographic effects are to be treated as necessary in institutional environmental impact statements.

Sincerely,

T C Byerly

T. C. BYERLY
Assistant Director
Science and Education

ASSISTANT SECRETARY

OFFICE OF THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

MAY 15 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Mr. Cushman:

My staff has reviewed the draft environmental impact statement for the space shuttle program. On the basis of their report, I have no adverse comment, in view of the precautions which are promised to warn merchant mariners and recreational boaters of the high overpressure that will be experienced from the sonic boom that will occur over the ocean in the focus area 60 kilometers down range from the launch site.

In view of the scale of the down range overpressure, it is suggested that the final statement identify in more detail the advance warning precautions and steps to be taken to monitor their observance.

Sincerely,

Herbert F. DeSimone
Assistant Secretary for
Environment and Urban Systems

ASSISTANT SECRETARY OF DEFENSE
WASHINGTON, D. C. 20301

HEALTH AND
ENVIRONMENT

6 JUN 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and Space
Administration
Washington, D. C. 20546

Dear Mr. Cushman:

The Draft Environmental Statement on the NASA Space Shuttle Program has been reviewed.

The Department of Defense concurs in the goals of the Space Shuttle Program and concludes that the statement provides an adequate evaluation of the environmental effects.

Detailed comments suggested by the Department of the Air Force are attached.

Sincerely,

John A. Busterud
Deputy Assistant Secretary of Defense
(Environmental Quality)

Attachment
a/s

AIR FORCE SUGGESTED CHANGES
TO THE
DRAFT ENVIRONMENTAL STATEMENT - NASA SPACE SHUTTLE PROGRAM

1. Page 4, Line 2:

Delete "from seven to 30 days"
Add "up to 30 days"

Specific Department of Defense missions are of shorter durations than seven days (e.g., a one orbit mission).

2. Page 18, Line 9:

Delete "Appropriate warnings will be issued prior to each reentry."

Although appropriate warnings will be issued whenever possible the nature of certain Department of Defense missions preclude the issuance of such warnings for these missions. However, warnings covering specific areas and extended time periods can be issued.

3. Page 76, Line 5:

Delete "small"

The word small is misleading in this context and not necessarily factual as operating costs are not that well known at the present time.

4. Page 86, Line 26:

Delete Para. 4b(3)

It is not clear that this paragraph is true when applied to specific Department of Defense missions.

Attachment 1

B64

THE ASSISTANT SECRETARY OF COMMERCE
Washington, D.C. 20230

May 25, 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics & Space
Administration
Washington, D. C. 20546

Dear Mr. Cushman:

The draft environmental statement for the "Space Shuttle Program," which accompanied your letter of April 19, 1972, has been received by the Department of Commerce for review and comment.

The Department of Commerce has reviewed the draft environmental statement and has the following comments to offer for your consideration.

NASA states that there will be high overpressures from focused sonic booms in a small area in the open ocean, down range from the launch site. The pressure shown in the report appears large and we are not sure that present techniques for "clearing" areas under rocket trajectories are adequate. With the proposed frequency of launches, the problem could become real. We suggest that a more active plan for patrolling and clearing hazardous areas might be given consideration.

While the ascent phase for this vehicle as proposed in the NASA Space Shuttle program is not significantly different from normal space missions of the type heretofore flown, the re-entry phase is quite different. Because the reuseable orbitor is a winged vehicle, it will re-enter at a substantially shallower angle than a ballistic type of re-entry vehicle and will spend a much longer period of time in the upper layers of the atmosphere. During the re-entry, it will, as the impact study notes, produce nitric oxide and leave certain metallic residues in the atmosphere. The degree to which the nitric oxide is formed will depend strongly on whether the ablating material of the nose cone is catalytic or anti-catalytic with regard to the recombination process which produces the nitric oxide, so that the amount produced will be a function of final vehicle design as well as flight profile. These are two questions of concern with regard to environmental impact on the upper atmosphere:

a) Do we fully understand the range of recombination processes which may affect the neutral upper atmosphere?

b) Has the effect of the re-entry profile with regard to the level of ionization in the upper atmosphere and the generation of traveling ionospheric disturbances been explicitly considered.

With regard to the first question, we know from laboratory experiments that a great variety of metastable compounds can be produced in the upper atmosphere: helium compounds, for example. We are curious as to whether the full range of such products has been considered in the study.

As to the second topic, we feel that the question should be raised as to the effect of the proposed re-entry profile on ionization levels in the upper atmosphere, particularly in the vicinity of the D, E, and F levels of the ionosphere. While the amount of ionization which will be produced by such a re-entry may be small, so is the total number of charged particles present prior to the re-entry. Is there any possibility that sufficient change in ionization level may be created to cause a significant effect on telecommunications or in solar-terrestrial relationships? Similarly, will the traveling ionospheric disturbances produced by the re-entry have a significant environmental effect?

We suggest that answers might be sought during the course of the program through suitable research. If the answers are already known then they could be presented in the statement.

We hope these comments will be of assistance to you in the preparation of the final statement.

Sincerely,

Sidney R Galler

Sidney R. Galler
Deputy Assistant Secretary
for Environmental Affairs

United States Department of the Interior

OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

JUN 2 1972

Dear Mr. Cushman:

Thank you for providing us with the opportunity to comment on the draft environmental statement on the NASA Space Shuttle Program (ER-72/492).

In general the statement presents a broad analysis of the various environmental impacts such as noise, rocket exhaust, and fuel loss resulting from testing, launching, and recovering the space shuttle. Although some detailed information is given, an adequate analysis of the various environmental effects will require the reader to assimilate much of the material listed in reference Appendix (B) and in various footnotes. We feel that the statement would be much improved if the pertinent detailed information were summarized in the statement itself. Specific comments follow:

No information is provided directly about the loss rate of the products of combustion from the stratosphere and higher layers (except particulates) either to outer space or lower atmospheric layers. Without such information, it is difficult to judge long-term compositional changes in the most rarified layers of the atmosphere resulting not only from this program but also from other space activities by this and other nations. A monitoring program might be proposed to provide information on loss rates of various species from these layers.

Reference is made to a private memorandum to NASA (Appendix (B), reference 10). It would be good policy in a statement of this sort to use only supporting documents which are available to the public and have had an opportunity to be subjected to the scrutiny of scientists and engineers competent in the field.

The last line on page 79. "Leaching" is an extractive treatment of solids. "Scrubbing" would be a more accurate term for the meaning intended.

The financial analysis presented in Appendix (A) is overly simplistic and does not apply discounted cash flow.

We believe that the subject project would affect only local populations of wildlife. However, we wish to point out the inaccurate assumption, on page 45, regarding the use of fish toxicity data. Data generated from toxicity studies involving fish should not be applied to birds.

Because launching, re-entry, and orbiter landing ranges are not identified for program operations at either Kennedy Space Center or Vandenberg Air Force Base, we are unable to determine whether or not the proposed Space Shuttle Program would have any adverse effects upon existing, proposed, or known potential units of the National Park System and historic, natural, and environmental education sites eligible or potentially eligible for registration in the National Landmark Programs.

For the expansion of existing facilities or the development of additional facilities at both Kennedy Space Center and Vandenberg Air Force Base, a detailed analysis of new construction and program operating effects upon natural, cultural, and esthetic environmental resources at the project sites and identification of project effects in terms of the five aspects of environmental analysis described in Section 102(2)(C) of the National Environmental Policy Act of 1969, would be appropriate.

In determining program effects upon natural and cultural values, surveys of natural, archeological, and historic resources may be needed to: (1) determine whether or not such values are present and, if so, their significance and extent; and (2) provide a basis for evaluating impacts.

The final statement would, also, provide an appropriate opportunity to indicate compliance with the National Historic Preservation Act of 1966 (80 Stat. 915), especially regarding consultation of the National Register of Historic Places as provided for in Section 106. The criteria for use in determining whether the project affects sites listed on the National Register is available in the Federal Register of March 15, 1972.

We suggest, also, that the final environmental statement offers a desirable opportunity to discuss agency response to Section 2(b) of Executive Order 11593 of May 13, 1971, entitled "Protection and Enhancement of the Cultural Environment."

Sincerely yours,

S. L. Lyon

Deputy Assistant Secretary of the Interior

Mr. Ralph E. Cushman, Special Assistant
National Aeronautics and Space Administration
Washington, D.C.
20546

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, D. C. 20410

OFFICE OF THE ASSISTANT SECRETARY FOR
COMMUNITY PLANNING AND MANAGEMENT

IN REPLY REFER TO:

MAY 25 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics & Space Administration
Washington, D. C. 20546

Dear Mr. Cushman:

This is in response to your request of April 19, 1972, for comment on the draft environmental statement on NASA's Space Shuttle Program as required by PL 91-190 and the guidelines of the Council on Environmental Quality. It is noted on page 2 that the "statement is limited to a treatment of the space shuttle as a transportation system for rapid, easy access to space for men and equipment, and covers the environmental effects associated with its development and eventual operations."

HUD defers to other agencies for environmental impacts associated with thermal and air pollution, atmospheric effects, and safety from jettisoning.

HUD is interested primarily in the effects on human settlements.

1. Historically, Federal programs have often resulted in disorderly growth and development of communities around Federal installations. The environmental impact statement for the space shuttle is incomplete in this regard, and cannot be considered complete until these environmental consequences are analyzed. Careful land use planning is essential. Notwithstanding page 19 to the contrary and brief references on page 70, we believe these analyses of expansions or modifications as a result of the space shuttle program should be circulated in draft to selected Federal agencies and local A-95 agencies and made part of the final environmental impact statement on the space shuttle program.

2. The treatment of noise effects is also incomplete. The statement notes on page 50 that the major source of noise is that generated by rocket engines during engine tests and launches. "The nature of this noise may be generally described as intense, relatively short duration, and spectrally composed of predominantly low frequency energy." Table 8, page 51, indicates dBA levels of 124 up to about 4 miles from the site and levels of 112 dBA up to 12 miles from the site. Table 9 contains damage risk criteria for controlled areas which would permit 139 dBA for 20 minutes.

We do not, however, find local maps showing the contours of the various dBA ratings which will impact near each affected NASA installation as a result of space shuttle activities or any indication of the extent to which human settlements (numbers of persons and houses) would be affected by this noise in either "controlled areas" or "uncontrolled areas." We believe such analyses are essential both because NASA could become liable under damage suits and because HUD under its new noise policy circular 1390.2 (copy attached) directs HUD field offices to avoid insurance of, or assistance to, new construction on sites with "unacceptable" noise environments as defined therein.

3. Similarly, the effects of the sonic boom of reentry upon human settlements are not located geographically or discussed fully. This should be done to the extent that the sonic boom will occur over land areas. If no sonic boom will occur over land areas, this should be stated.

Thank you for the opportunity to comment on the environmental impact of this important program. We look forward to discussing these points informally before the final environmental impact statement is circulated.

Sincerely,

Richard H. Broun
Acting Deputy Director,
Office of Community and
Environmental Standards

Enclosure

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20201

JUN 8 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and
Space Administration
Washington, D. C. 20546

Dear Mr. Cushman:

This is in response to your letter dated April 19, 1972, wherein you requested comments on the draft environmental impact statement for the NASA Space Shuttle Program.

This Department has reviewed the health aspects of the above program as presented in the documents submitted. The program does not appear to represent a hazard to public health and safety.

The opportunity to review this draft environmental impact statement is appreciated.

Sincerely yours,

Merlin K. DuVal, M.D.

Merlin K. DuVal, M.D.
Assistant Secretary for
Health and Scientific Affairs

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

APR 28 1972

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and
Space Administration
Washington, D.C. 20546

Dear Mr. Cushman:

Please refer to your request for AEC comments on the following Draft Environmental Statement: NASA Space Shuttle Program.

We have no comments on this Draft Statement. Thank you for giving us this opportunity.

Sincerely,

Lester Rogers

Lester Rogers, Director
Division of Radiological and
Environmental Protection

cc: G. A. Blanc, REP
R. J. Catlin, DEA

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 2 8 1972

OFFICE OF THE ADMINISTRATOR

Mr. Ralph E. Cushman
Special Assistant
Office of Administration
National Aeronautics and Space
Administration
Washington, D.C. 20546

Dear Mr. Cushman:

Thank you for the opportunity to review the draft environmental impact statement prepared on the Space Shuttle Program. Our detailed comments are enclosed.

In general, we agree that the Space Shuttle Program can probably be conducted without unacceptable long-term risk to the environment. Operations associated with this program, however, may result in some short-term local air quality and noise problems. We recommend that these problems, identified in the enclosed comments, be discussed in the final environmental statement.

If you have any questions on our comments or on related environmental matters, please let us know.

Sincerely,

Sheldon Meyers

Sheldon Meyers
Director
Office of Federal Activities

Enclosure

DETAILED COMMENTS ON THE DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR THE NASA SPACE SHUTTLE PROGRAM

The draft statement indicates that the solid-fuel booster system to be employed will emit large quantities of hydrogen chloride (HCl), carbon monoxide (CO), chlorine (Cl_2) and aluminum oxide (Al_2O_3). It is not expected, however, that HCl, CO or Cl_2, emitted in the quantities specified, will present any significant environmental problems unless vehicle launches occur during adverse meteorological conditions such as: rain, minimum atmospheric dispersion, or air stagnation. The final statement should indicate what effect such conditions would have on the ability of space shuttle operations to meet the National Primary and Secondary Air Quality Standards. In addition, the final statement should discuss operational methods that could be employed to avoid air quality problems.

In our opinion, emissions of Al_2O_3 in particulate form will result in initial down-wind concentrations that will be substantially higher than levels specified in appropriate standards. The significance of the environmental impact due to Al_2O_3 or the persistence of excessively high concentrations of this substance cannot be determined from the information provided in the draft statement. The statement indicates that the average particulate size will be approximately 10 microns, but fails to provide size distributions. Such information should be provided in the final statement. In addition, the environmental effects of the deposition of particulates and the amount of land area likely to be affected, should be evaluated in the final statement.

We recommend that NASA establish an environmental monitoring program to confirm the theoretically predicted emission levels and down wind concentrations of all potentially hazardous gases and particulates. Also, we suggest a monitoring program and additional studies be supported by NASA to assure that the program will have no irreparable adverse effect on the stratosphere. The final statement should describe any such programs or studies that will be instituted.

The draft statement does not provide information on the actual impact of vehicle noise and sonic boom on humans and wildlife. The effect of high sound levels on the health and well being of all susceptable forms of life near the launch complex or along the flight paths should be described in detail in the final statement.

The statement implies that the sonic boom over-pressures arising from orbiter re-entry, ranging from 0.5 psi to 2 psi., will cause only nuisance or annoyance. It has been observed during aircraft overflight studies, however, that nonstructural damage to buildings frequently occurs as a result of exposure to sudden over-pressures of 1 to 2 psi. In addition to providing more details on this problem, the final statement should resolve the apparent discrepancy that exists between the assessments of the effects at sonic booms made on page 59 and page 69 of the draft statement.

The summary provided in the draft statement describes the potential impact of the Space Shuttle Program as "...small, ...local, ..., (and) controllable. With regard to noise problems, however, no information is included on the methods to be employed to control the extent of the adverse effects. Information on these methods should be provided in the final statement.